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UNIVERSITY OF PENNSYLVANIA

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THE APPLICATION OF THE METHOD OF COMPARISON TO THE PROBLEM OF MEMORY CHANGES

BY FRANCIS W. IRWIN AND MORTON A. SEIDENFELD

University of Pennsylvania

During the past fifteen years two lines of research, which had previously been pursued sporadically and without full realization of their importance, have been revitalized by their treatment at the hands of the Gestalt psychologists. On the one hand, the problem of memory changes was brought to the fore in 1922 by Friedrich Wulf's well-known paper [1] which purported to show that with the passage of time certain structurally-conditioned distortions appear in memorial reproductions. Work so interesting and so important for theory was soon continued and extended by numerous investigators, most of whom are referred to in Warner Brown's convenient summary.[2] The method common to these experiments may be called the 'method of reproduction,' since the Ss are required to draw by hand reproductions of visually perceived figures at various intervals of time after the original exposure.

On the other hand, a year after Wulf's paper there appeared an equally important study by Köhler,[3] illuminating

[1] Wulf, F, Ueber die Veränderung von Vorstellungen (Gedächtnis und Gestalt). *Psychol. Forsch.*, 1922, 1, 333–373.

[2] Brown, W. Growth of 'memory images.' *Amer. J. Psychol.*, 1935, 47, 90–102.

[3] Köhler, W. Zur Theorie des Suksessivvergleichs und der Zeitfehler. *Psychol. Forsch.*, 1923, 4, 115–175.

the problem of the time-error of successive comparison. Köhler's dynamic interpretation of this familiar phenomenon likewise instigated a long series of experiments, as can be seen in Needham's review.[4] The method of comparison as employed in time-error experiments involves the presentation of stimuli for judgment, usually in pairs each of which consists of a standard and a comparison stimulus separated by a relatively short period of time.

Up to the present time little use has been made of methods developed from those of psychophysics in dealing explicitly with problems of memory. Some students of the time-error, notably Lauenstein [5] and Pratt,[6] have recognized the possibility that a relationship may exist between the time-error and the so-called memory changes. In his elaborate discussion of trace theory, which draws upon data from both fields, Koffka [7] mentions an attempt of his to apply the method of comparison to the memory problem which unfortunately led to inconclusive results. In general, however, the two lines of research have been pursued independently.

Directly relevant experimental findings appear to be confined to one or two early papers. Baldwin and Shaw,[8] in 1895, attempted to determine the accuracy of 'memory for square size,' using methods which today might be called the methods of recognition, of comparative judgment, and of reproduction. By all three methods a decrease in the accuracy of memory with increased time was found, the intervals being 10, 20 and 40 min. Only the last of the three sets of results was reported in such form as to enable one to determine directions of change; here the Ss' drawings became smaller with lapse of time, which is explained by the authors as probably due to fatigue or the small size of the paper on which the drawings were made. At the same time Warren and

[4] Needham, J. G. The time-error in comparison judgments. *Psychol. Bull.*, 1934, 31, 229–243.

[5] Lauenstein, O. Ansatz zu einer physiologischen Theorie des Vergleichs und der Zeitfehler. *Psychol. Forsch.*, 1932, 17, 130–177.

[6] Pratt, C. C. The law of disuse. *Psychol. Rev.*, 1936, 43, 83–93.

[7] Koffka, K. *Principles of Gestalt Psychology.* N. Y., 1935, p. 497.

[8] Baldwin, J. M., and Shaw, W. J. Memory for square size. *Psychol. Rev.*, 1895, 2, 236–239.

Shaw [9] reported results, obtained by a comparison method, which failed to agree with the findings of Baldwin and Shaw and which seemed to the writers to indicate that "*the memory-image tends to grow larger* as the time interval increases" (p. 241, italics in original). They attempted to explain these results by means of Weber's law. The tentative beginnings represented by these two experiments led to no sustained attack upon the problem, no doubt because of the meagerness of related fact and theory at the time. They are, so far as the writers of the present paper have been able to discover, the only definite results on memory changes secured by psychophysical methods.

Our purpose in this paper is to exhibit some results obtained by means of a method designed to attack the memory change problem with the resources of psychophysics, and to bridge the gap still separating memory phenomena from those of the time-error.

METHOD

The method used was that of successive comparison, slightly modified from its usual form in order more closely to approximate the conditions of the memory experiments. Six simple figures (see Fig. I) were exposed visually, one at a time, to groups of Ss. The exposure apparatus consisted of a ply-wood board 38 cm by 94 cm, painted flat black, with a centered aperture 20.3 cm square, the whole serving as a frame for the cards to be exposed. The board was set with the long side horizontal, and was kept in an upright position by two small triangular wings behind it at right angles. By means of grooves on the reverse side of the board heavy cards of drawing board, about 24 cm square, could be slid past the aperture. A blank white card filled the aperture except when a figure was being exposed. To expose a figure, the card was inserted into the grooves, and then slid over to the aperture, automatically pushing before it the blank card until the latter reached a stop button. This button was situated in such a way as to arrest the two cards when the figure was properly centered in the aperture. The blank card was then removed, and a card with the second figure upon it was inserted. This card was shoved over to replace the first figure, just as the first card had replaced the blank; and so on until all of the figures had been exposed. The last figure was then replaced by a blank card. The grooves were so arranged that the operations of replacing cards, and the unexposed and previously exposed cards themselves, were invisible to the Ss. With very little practice the experimenter was able to perform these simple operations with proper regard to the exposure times.

In order to have a supply of identical material, photographic reproductions of carefully drawn figures were made, and mounted upon heavy white drawing board. Each figure was centered on its card. The figures were of the following descriptions:

[9] Warren, H. C., and Shaw, W. J. Further experiments on memory for square size. *Psychol. Rev.*, 1895, 2, 239–244.

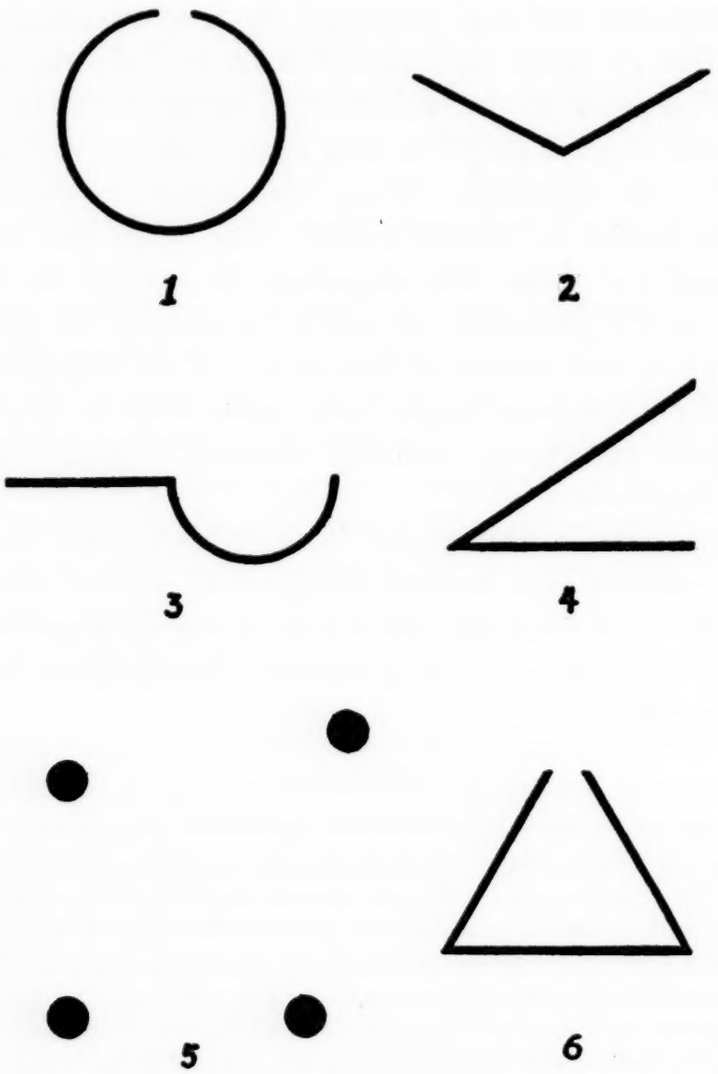


FIG. I. 1. Open circle; 2. Obtuse angle; 3. Arc-line figure; 4. Acute angle; 5. Dot figure; 6. Open triangle.

No. 1. Open circle: diameter, 73 mm; gap at top; 11.5 mm chord (arc of 18 degrees).

No. 2. Obtuse angle: limbs, each 53 mm; angle of 122 degrees; angle opening directly upward.

No. 3. Arc-line figure: horizontal line, 54.5 mm; semicircle attached to right extremity of straight line, diameter 50 mm.

No. 4. Acute angle: open toward upper right, lower limb horizontal; angle 34 degrees; upper limb, 92 mm; lower limb, 75 mm.

No. 5. Dot figure: four dots disposed as approximate square with eccentric upper right hand corner; base, 75 mm between centers of dots; left side, 75 mm; base and left side at right angle; right side, 90 mm; top side, 90 mm; diameter of dots, 12 mm.

No. 6. Open triangle: base, 73 mm; sides, each 63 mm; gap width, 12 mm; figure bilaterally symmetrical, with gap at top.

The width of the lines in these figures was 3–3.5 mm.

These figures were selected for their simplicity, for clarity of specific characteristics, for similarity to those used in previous investigations, and for usefulness in memory theory.

The following instructions were read to the Ss:

> I am going to show you several different figures. I want you to observe them very carefully while they are exposed, so that if I show you some similar figures in the future you will be able to compare them with these. Remember, look at each figure as long as it is shown, but do not write or draw anything or talk to your neighbor about it.

The six figures were shown one at a time for 5 sec. each. Each S was then given a record sheet, with spaces for name, age, sex and date. Below this were three columns, the first containing the numbers from 1 to 11, and the second and third containing opposite each other the names of the two categories of judgment between which the S was required to choose for each of his 11 judgments. We reproduce below, in the first, third and fourth columns these three columns of the record sheets. The second column below *was not found on the record sheets*, but is given here to indicate to the reader the characteristics of the figures upon which judgments were made.

1. (Fig. 1, width of gap)	WIDER	NARROWER
2. (Fig. 1, area)	LARGER	SMALLER
3. (Fig. 2, angle)	GREATER	LESS
4. (Fig. 3, length of straight line)	LONGER	SHORTER
5. (Fig. 3, curvature of arc)	MORE CURVED	LESS CURVED
6. (Fig. 4, length of short line)	LONGER	SHORTER
7. (Fig. 4, angle)	GREATER	LESS
8. (Fig. 5, area)	GREATER	LESS
9. (Fig. 5, 'squareness')	MORE NEARLY SQUARE	LESS NEARLY SQUARE
10. (Fig. 6, width of gap)	GREATER	LESS
11. (Fig. 6, area)	GREATER	LESS

As will be observed in this table, no intermediate category of judgment was permitted. This procedure, common to many psychophysical experiments, was followed here because preliminary experiments had shown that Ss tended to include in a middle category not only true 'equal' judgments, but also a large number of 'doubtful' judgments. Such a tendency results, of course, in a considerable diminution of the apparent asymmetries of distribution, and increases the number of Ss needed to establish trends.

The record sheets having been handed out, the experimenter read the following instructions to the Ss three minutes after the exposure of the last figure:

> This is an experiment dealing with small differences. I am going to show you some figures more or less similar to those you have already seen. As I show you each figure I shall ask you one or two questions about it. Each question can be answered by underlining the proper word on your answer sheet. You will see that there are two possibilities indicated on the answer sheet for each question; you must make a choice between them, and underline one of them no matter how hard it may be. If you are entirely undecided, please guess as well as you can, so as not to omit any answer.

Figures *identical* to those first exposed[10] were then shown, in the same order. They were exposed as long as was necessary for all Ss to come to a decision, usually 10–20 sec. As the first figure was exposed the experimenter said:

> Please compare this figure with the one like it that you were shown originally. Now underline in line 1 on your answer sheet the word that best answers the following question: Is the gap in *this* figure *wider* or *narrower* than the gap in the original figure?
>
> When all Ss had made their choice, the experimenter said:
>
> All right. Now please indicate in line 2 the best answer to the question: Is *this* figure *larger* or *smaller* than the original figure?

The judgments having been made, the next figure was exposed, the appropriate question was asked, and so on until the 11 judgments were completed. A few minutes were then allowed to pass without any activity concerned with the experiment except the collection of the record sheets. More record sheets, identical to the first ones, were then given to the Ss. The experimenter said:

> I am going to show you some more figures more or less similar to those I first showed you. I want you to observe them as before, and answer the questions I shall ask by underlining your choice as before. *Please remember that you are to compare these figures with the very first figures I showed you, and* NOT *with those you saw in the meantime.*

The same figures were then shown once more, and the same questions asked. The procedure was timed so that the first figure was shown very nearly 10 minutes after the completion of the original (first) exposures. Record sheets were collected as before. No questions about the experiment were answered, in order that the Ss might be given no information about its purpose.

Seven days later a similar procedure was carried out, using the same instructions as for the 10 minute procedure, and exposing the figures in the same order.

In this manner results were obtained from 70 Ss, each of whom gave judgments at each of the three time intervals. This group of Ss will be referred to as Group I. Another group of Ss, 97 in number, was subjected to a procedure exactly the same as that described with the exception that the figures were exposed, and the questions were asked, in an order just the reverse of that used for Group I. These Ss compose our Group II. The total number of Ss here reported on is thus 167. The results were obtained in undergraduate classes, Group I being composed of four classes numbering 8, 13, 23 and 26 members, and Group II of three classes of 20, 33, and 44 members. Of the 167 Ss, 92 were men and 75 were women. The work was done in the Laboratory of Psychology of the University of Pennsylvania during the academic year 1935–36.

Results and Discussion

In Table I are found the results for the 167 Ss, Groups I and II combined. The first three columns of this table indicate the serial number of the judgment, the figure, numbered as in Fig. I, and the characteristic on which judgment was

[10] The usefulness for many purposes of a 'method of equal stimuli has been suggested by Arons and Irwin. See Arons, L., and Irwin, F. W. Equal weights and psychophysical judgments. *J. Exper. Psychol.*, 1932, 15, 733–751.

TABLE I

PERCENTAGES OF 'GREATER' JUDGMENTS FOR EACH FIGURE FOR EACH TIME INTERVAL. GROUPS I AND II COMBINED (167 Ss)

Judgment Number	Figure	Characteristic	Percent 'Greater' Judgments			Critical Ratios		
			3 min.	10 min.	7 days	3 min.	10 min.	7 days
1	1	Gap	72.5	61.1	64.7	5.6	2.8	3.7
2	1	Area	56.3	59.9	56.9	1.6	2.5	1.7
3	2	Angle	66.5	64.7	61.7	4.1	3.7	2.9
4	3	Length of straight line	**40.7**	**41.3**	**48.5**	2.3	2.2	0.4
5	3	Curvature of arc	72.5	55.1	59.3	5.6	1.3	2.3
6	4	Length of short line	**49.7**	61.7	58.1	0.1	2.7	2.0
7	4	Angle	50.9	**40.7**	**43.7**	0.2	2.3	1.6
8	5	Area	**49.1**	**46.1**	**49.7**	0.2	1.0	0.1
9	5	Squareness	**46.7**	**38.9**	**34.7**	0.8	2.8	3.8
10	6	Gap	61.1	55.7	55.1	2.8	1.4	1.3
11	6	Area	**43.1**	**30.5**	**38.9**	1.7	4.9	2.8

made. The fourth, fifth and sixth columns give the percentages of judgments in the direction of 'greater' (wider gap, greater area, wider angle, longer line, etc.) for each characteristic at each of the three intervals (3 min., 10 min., and 7 days respectively). Since no intermediate category of judgment was permitted, the percentage of 'less' judgments is always equal to 100 percent minus the given percentage of 'greater' judgments. For the sake of ease in reading the table, those percentages which are less than 50 percent are printed in bold type. As we wish to stress the direction of asymmetry rather than the absolute value of these percentages, an index of the reliability of the difference between each percentage and 50 percent has been calculated. The standard error of the percentage 50 percent when n equals 167, as given by the formula $\sigma_p = \sqrt{pq/n}$, is 4 percent. If a percentage of 72.5 is obtained, as in the judgments on characteristic 1 at the 3 min. interval, this percentage differs from 50 percent by 22.5 percent, which is 5.6 times the standard error 4 percent. The critical ratios computed in this way for each of the percentages of columns 3, 4 and 5 are presented in columns 7, 8 and 9 of Table I.

In Fig. II the percentages of greater judgments of Table I are shown graphically. The 11 graphs of this figure represent the results for the 11 judged characteristics, a point being plotted for each of the three intervals. It should be noted

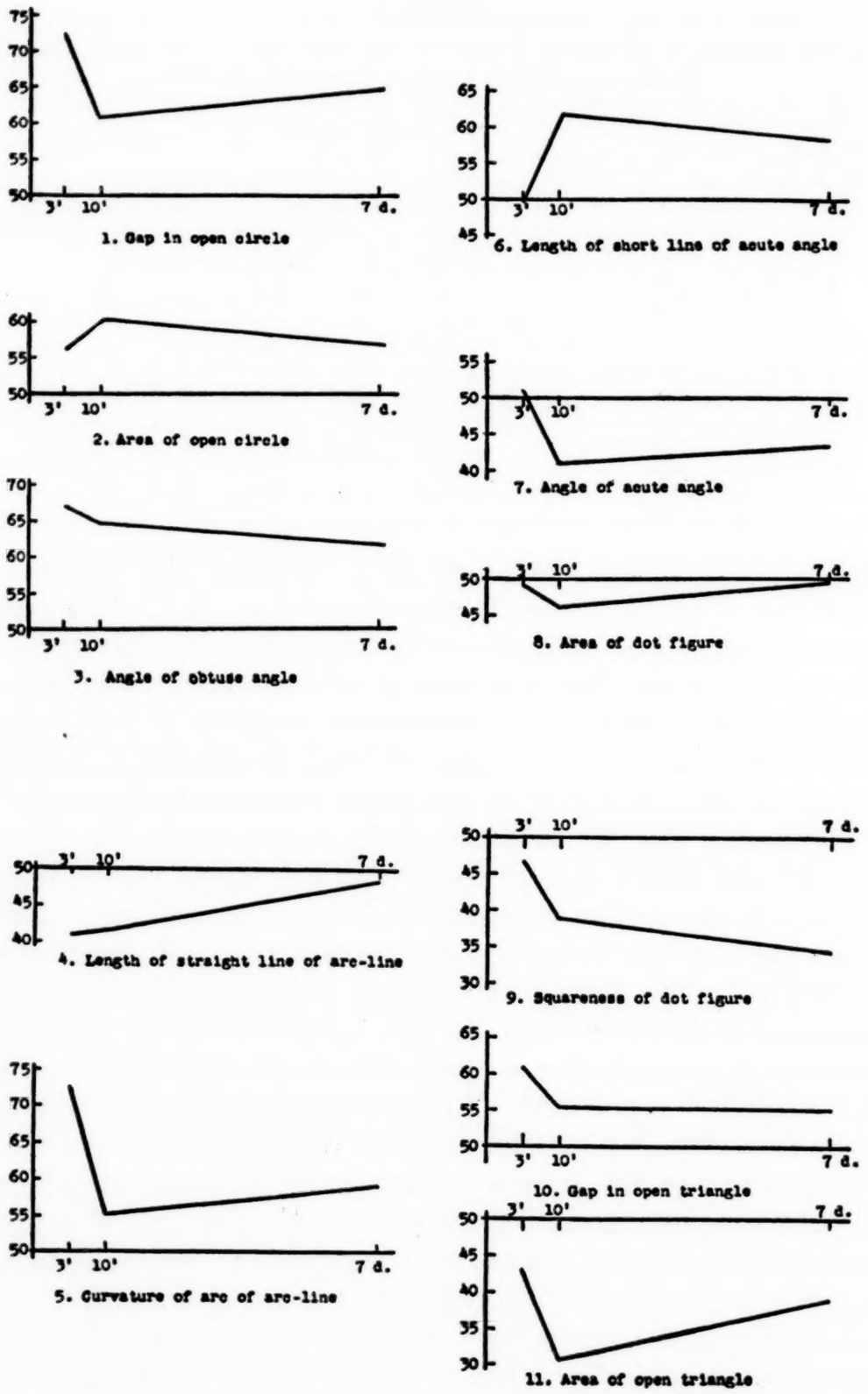

1. Gap in open circle
6. Length of short line of acute angle
2. Area of open circle
7. Angle of acute angle
3. Angle of obtuse angle
8. Area of dot figure
4. Length of straight line of arc-line
9. Squareness of dot figure
5. Curvature of arc of arc-line
10. Gap in open triangle
11. Area of open triangle
3' 10' 7 d.

FIG. II. Curves drawn from the percentages of 'greater' judgments on each judged characteristic after each time interval.

that on the axis of abscissas the space between the 3 min. and 10 min. exposures as compared with that between the 10 min. and 7 day exposures is too large to represent accurately the actual time relations (approximately 1 : 1440). To indicate the direction of asymmetry we have drawn the axis of abscissas for the ordinate 50 percent; thus points above this axis represent asymmetry in the direction of 'greater' (corresponding to a 'negative' time-error), and points below it, asymmetry in the direction of 'less' (corresponding to a 'positive' time-error).

Inspection of the results as shown in Table I and Fig. II shows immediately that significant asymmetries do exist, when by the term 'asymmetry' we mean a failure of the judgments to be distributed equally into the two categories. Evidence of this is the large number of high critical ratios, 19 of the 33 being 2 or over, and 7 of these 19 being above 3.5. Then, too, there is a high degree of consistency of direction of asymmetry at the three time intervals for each characteristic. Observation of the graphs shows that in only two cases is there a lack of such consistency of direction, namely, at the 3 min. interval for judgments 6 and 7 as compared with the later judgments; and the two points in question lie very near 50 percent. Considering both amount and consistency, the presence of genuine asymmetry can be claimed with confidence in the case of all of the judged characteristics with the possible exception of No. 8 (area of dot figure), where there is consistency but small and unreliable divergences from 50 percent.

Further, the asymmetries cannot be the result of some general influence pervading the experiment independent of the judged characteristics themselves, since they are in opposite directions in the case of different characteristics. For example, a tendency toward overestimation is shown in judgments 1, 2, 3, 5, 6 and 10, and the opposite tendency in judgments 4, 7, 7, 9 and 11. The fact that overestimation appears largely in the lower-numbered judgments, and underestimation in the higher-numbered judgments, cannot be held to signify the presence of an effect due to the order of judgments since, while 70 Ss made their judgments in the order indicated

by these numbers, 97 Ss made their judgments in the opposite order. We conclude, then, that the asymmetries are specific to the individual figural characteristics judged by the Ss.

A great practical advantage of the method used in this experiment lies in the obtaining of results from groups. This has potential disadvantages, however, at least one of which we need to examine closely. The use of fairly large groups meant that Ss observed the exposed figures from considerably different distances. We have classified 116 of our Ss into two groups: 62 cases (Group A) were 40 to 175 inches from the exposure apparatus, while 54 cases (Group B) were 175 to 320 inches distant. The results for these two groups separately are given in Table II. In adjacent columns of this table

TABLE II

THE PERCENTAGES OF 'GREATER' JUDGMENTS MADE BY GROUPS A AND B ON EACH CHARACTERISTIC AT EACH TIME INTERVAL, AND THE DIFFERENCES BETWEEN THE CORRESPONDING PERCENTAGES FOR THESE TWO GROUPS (GROUP A–GROUP B)

Group A: 62 Ss, 40″ to 175″ distant from exposed figures
Group B: 54 Ss, 175″ to 320″ distant from exposed figures

Characteristic Number	3 min.			10 min.			7 days		
	Group A	Group B	Diff.	Group A	Group B	Diff.	Group A	Group B	Diff.
1	89	70	19	68	67	1	63	54	9
2	55	56	− 1	55	65	−10	56	61	− 5
3	73	56	17	74	52	22	68	61	7
4	34	41	− 7	45	39	6	45	48	− 3
5	68	78	−10	55	65	−10	56	67	−11
6	52	50	2	63	63	0	45	72	−27
7	47	57	−10	50	37	13	52	43	9
8	47	52	− 5	37	41	− 4	45	59	−14
9	52	41	11	42	46	− 4	42	35	7
10	65	78	−13	53	61	− 8	58	54	4
11	47	43	4	24	33	− 9	37	43	− 6

(columns 2 and 3, 5 and 6, and 8 and 9) are the percentages of greater judgments made by Groups A and B respectively; following each pair of percentages is the difference in percentage between the two values concerned, obtained by subtracting the value for Group B from that for Group A. It should be noted that Table II represents only 116 of the 167 Ss whose results are found in Table I, data being absent for the

remainder of the main group. Hence Tables I and II need show no absolute numerical agreement.

The following information may be gained from this comparison:

1. The differences range from 0 percent to 27 percent in absolute value, with a median of 8 percent.

2. Of the 33 differences, 18 are positive, 14 are negative, and 1 is zero.

3. No definite tendency toward association of the direction of asymmetry with the sign of these differences is shown.

4. In 6 of the 33 comparisons a difference in the direction of asymmetry for Groups A and B is shown. Most of the 12 percentages involved in these 6 comparisons indicate relatively small amounts of asymmetry, only two being outside of the range from 40 percent to 60 percent. The most striking divergence is that for characteristic No. 6 at 7 days, where the values are 45 percent for Group A and 72 percent for Group B.

In general, the differences between the two groups, while by no means negligible, are not so great as we had feared might be present where such large differences in distance existed. Although they probably contribute to the heterogeneity of the statistical populations, and therefore to variability, they seem not to introduce into the experiment any considerable systematic error. Although no direct evidence is at hand, we might speculate that the phenomena of 'constancy of size' have come to our assistance here. At any rate, the differences between the two groups seem not to be of such a nature as to disturb the theoretical conclusions to be drawn from the results.

Our primary interest in the results of this experiment, aside from questions of method, lies in their possible bearing upon the theory of memory. To pave the way for a discussion of this topic two points must be considered.

First, for the sake of clarity we shall refer to the figures used in the experiment by the names employed above in describing them, rather than simply by number. We are by

no means unmindful of the importance of the distinction between the figures as physical objects and the perceptions of the figures, nor of the possible ambiguity of the word 'figure' itself. The discussion will be clear, we believe, if it is understood that the word 'figure,' or the specific term 'open circle,' for example, is intended to refer to the physical objects here used as stimuli. Too much confusion has already been introduced into the literature on this and similar problems by neglect of this distinction or failure to make explicit the way in which terms are to be understood; we shall do our best to avoid contributing toward this confusion.[11]

Second, in relating our results to those obtained by methods involving drawn reproductions, it must be kept in mind that our Ss were always required to judge an exposed figure against the one *first* shown. Thus, a judgment of 'narrower' on the gap in the open circle was a judgment that the gap in the present figure was narrower than that in the original figure. From the point of view of trace theory, remembering that the two gaps were objectively equal, this judgment could be taken to mean that the 'gap in the trace' had grown *wider* during the interval, so that the gap now seen appeared *narrower*. Under the same conditions, if the S were asked to reproduce the original figure by drawing, he would be expected to draw a figure in which the gap was *wider* than that of the original. A judgment of 'narrower,' or in general, of 'less,' is therefore analogous to a drawn reproduction in which the characteristic in question is 'wider,' or in general, 'greater'; and vice versa.

To make as plain as possible the trends of the results, and to avoid circumlocution, Table III has been developed. The first column of this table names the characteristics which were judged. The second column states the direction of asymmetry of the judgments on each characteristic. The word 'positive' means a preponderance of 'less' judgments, and the word 'negative' a preponderance of 'greater' judgments, after

[11] It may be mentioned that we have at hand results of further experimentation which indicate that the names we have applied to our stimulus objects in most cases differ little in wording or meaning from names applied by Ss to what they see when they observe these stimulus objects. Until publication of these results, however, we do not wish to bind ourselves to specific assumptions about the nature of the Ss' perceptions.

the convention established by Fechner for the psychophysical time-error. The third column re-states the general trends of the results as if the judgments had been made with the present figure as the standard stimulus and the original figure as the comparison stimulus, instead of the reverse. We assume here simply that the judgment, "This gap is wider than the one I first saw," means the same as the judgment, "The gap I first saw was narrower than this one." The first entry in this column, 'original gap narrower,' signifies that the majority of Ss gave judgments at the three time intervals which, re-stated, meant that the original gap seemed narrower than the one now exposed.

TABLE III

TRENDS OF RESULTS FOR EACH JUDGED CHARACTERISTIC

Characteristic	Direction of Asymmetry	Trend when Original Figure is Taken as Comparison Stimulus
1. Width of gap of open circle	Negative	Original gap narrower
2. Area of open circle	Negative	Original area less
3. Angle of obtuse angle	Negative	Original angle smaller
4. Straight line of arc-line	Positive	Original line longer
5. Curvature of arc of arc-line	Negative	Original arc less curved
6. Short line of acute angle	Ambiguous at 3 min., positive at 10 min. and 7 days	Little change at 3 min., original line greater at 10 min. and 7 days
7. Angle of acute angle	Ambiguous at 3 min., positive at 10 min. and 7 days	Little change at 3 min., original angle greater at 10 min. and 7 days
8. Area of dot figure	Slightly positive	Original area greater (?)
9. Squareness of dot figure	Positive	Original squareness greater
10. Gap of open triangle	Negative	Original gap narrower
11. Area of open triangle	Positive	Original area greater

A number of these results appear to agree strikingly with what is to be predicted from the law of Prägnanz and its special case, the law of closure. It is clear from Table III that the original gaps in the two open figures, the circle and triangle, tend to be underestimated, tempting us to conclude that a change in the direction of closure has taken place in the traces established at the time of the first exposure of the figures. Furthermore, the overestimation of the squareness of the original dot figure after a lapse of time, as found in the results, is easily accounted for: by the law of Prägnanz the trace should, *ceteris paribus*, approximate more nearly the 'good gestalt' of a square. The conditions for such a change

may have been improved by the fact that the term 'square' was used by the Ss in making their judgments. It so happens that these three cases, the results for which harmonize so beautifully with the expectations set up by Gestalt theory, are also the three cases in which prediction of direction of change can be made with relatively little reliance upon accessory assumptions.

For the other cases, however, it is not so clear what predictions should be made. This is due partly to the difficulties of the theory itself, as in instances where one cannot decide on *a priori* grounds whether to expect 'sharpening' or 'leveling'; and partly, we must admit, to our lack of information about the nature of the figures *as perceived.* This lack of information makes prediction uncertain since in Gestalt theory, as Koffka [12] insists, behavior is conceived of as regulated by the 'behavioral,' rather than by the 'geographical' environment. But stimulus figures are features of the geographical environment; only as *perceived* do they enter the behavioral environment. If, nevertheless, we allow ourselves for the moment some latitude of hypothesis, we might assume from our own perceptions of the figures that both the obtuse and acute angles were perceived as 'angles departing from a right angle.' In this case, the results (except for the ambiguous result for the acute angle at 3 min.) agree with the expectation that the obtuse angle, so to speak, should become smaller, and the acute angle larger. Of our three sets of results on the characteristic of area, those for the open circle seem to indicate 'shrinking,' and those for the open triangle and the dot figure (the latter indecisively), 'expansion.' The dot figure was the largest of our six figures, followed in order by the open circle and open triangle. Allport [13] obtained results by the method of reproduction which led him to the conclusion that "shrinkage with time is one of the definitely 'dynamical' properties of traces." Discussing this conclusion, Koffka [14] says: "Since none of the

[12] Koffka, *op. cit.*, Chapter II. Wulf had pointed out the importance of the Ss' 'Auffassung' of the figures.

[13] Allport, G. W. Change and decay in the visual memory image. *Brit. J. Psychol.*, 1930–31, 21, 133–148.

[14] Koffka, *op. cit.*, 499–500.

other investigators found this change, it must be confined to certain definite ranges of size. One might, however, expect that very small figures would manifest the opposite tendency, *i.e.*, to expand." Our results show that the size of the figure cannot be the sole factor determining the direction of change of area, and is perhaps not the most important one. In the arc-line figure, the shortening of the straight line (which was physically longer than the diameter of the semicircle) and the lessening of the curvature of the semicircle might possibly be interpreted as leveling, but could with equal probability have resulted from some such influence as object-assimilation. The short line of the acute angle becomes shorter (at 10 min. and 7 days); we offer no hypothesis to account for this. There is nothing, then, in the directions of the asymmetries found in the case of the eight characteristics discussed in this paragraph which is directly contrary to the principles of Gestalt theory. It must be only too evident, however, that the suggested hypotheses are almost purely *ad hoc*, and that the facts themselves are not adequate to decide the theoretical issues. Although they seem to us to be interesting and suggestive facts, additional knowledge is needed to make them crucial.

Summarizing the discussion for all eleven characteristics, it may be concluded that where definite expectations could be set up in advance (and were actually so set up in the minds of the experimenters when the figures were chosen), the directions of asymmetry found in the results meet the requirements of the laws of Prägnanz and closure. Where definite expectations were not possible, there appears in the results nothing which prohibits interpretations of the same kind, although of course there is nothing decisively in their favor.

Further analysis, however, brings to light an aspect of the data which offers considerable resistance to explanations in terms of Gestalt trace-theory. One of the most important findings of Wulf and his successors was the tendency toward progressive change in the direction set by the first reproduction. This finding was especially significant because it seemed to require a 'dynamic' type of explanation, and has been reported even by an author not sympathetic with Gestalt

interpretations.[15] A glance at our Fig. II, however, will show that in only one of the eleven curves (that for the squareness of the dot figure) is there a continuous increase of asymmetry with increased time, although in three cases (angle of acute angle, length of straight line of arc-line figure, gap of open triangle) there appears a continuous decrease of asymmetry. The general failure of our results to show progressive change with lapse of time constitutes their most striking deviation from the results of the methods relying upon drawn reproductions.

Is this difference to be accounted for by some inadequacy of the present experiment? Is it, for example, the result of forgetting (or lessened 'availability of traces'), leading to more guessing on the part of the Ss, and hence, since guesses will be distributed equally by chance into the two categories of judgment, to less asymmetry? Koffka [16] has distinguished three possible causes of lack of communication with old traces: "(1) The trace has disappeared, (2) the trace cannot exert an influence upon the present occasion, (3) the present occasion cannot communicate with the trace." The presence of significant asymmetries seems to rule out all three of these possibilities; as for the last two in particular, it is not unreasonable to suppose that the method of comparison, involving as it does the actual exhibition of the stimulus figures at the time of recall, is more likely to establish firm communication with old traces than a method using unaided reproductions. As a matter of fact, Wulf, in his experiment, was obliged to display parts of his original figures after the longer intervals in order to establish any communication at all. We therefore believe that the factor of uncertainty or guessing was probably less important in our results than in those of Wulf and the others who used his method. This, of course, leaves open the question as to how important such a factor may have been in *both* types of experiment.

We give a similar answer to the question: is it perhaps the influence of the processes of perception and judgment at one

[15] Gibson, J. J. The reproduction of visually perceived forms. *J. Exper. Psychol.*, 1929, 12, 1–39.

[16] Koffka, *op. cit.*, 522–528. Following quotation from p. 523.

exposure which distorts these processes at a later exposure? We should be willing to argue that the process of observing and judging a figure as performed by our Ss is simpler and more straightforward than the process of attempting to recall without visual cues a figure exposed previously and to draw by hand an accurate reproduction. We asked our Ss at the time of each judgment to compare the figure now shown with the very first of its kind shown, and not with others they had seen in the meantime; and it may very well be that we asked an impossibility. But whatever grounds may be given for its being an impossibility seem equally applicable to the drawing of a reproduction which shall not be influenced by a previous drawing. On neither Wulf's side nor ours is anything very definite known about the influence of previous judgments or drawings. Experiments are badly needed in which comparisons can be made of results obtained both with and without intervening formal recall. That such experiments have not yet been performed by others is perhaps for the same reason that we do not report one here: the great practical difficulty of obtaining sufficiently large and homogeneous groups of subjects.

On logical grounds, then, the two methods seem to be on the same footing with respect to the possible effects of previous experiences, while the method of comparison appears to have an advantage over that of reproduction in more easily establishing communication with old traces. We suspect also, from experience with psychophysical method, that in the method of comparison there is likely to be less of the verbal analysis that has been reported by the students of memory changes. The whole situation will be more satisfactory when the questions we have raised can be answered by experimental evidence. At any rate, we do not see that our failure to find progressive changes can be attributed to either of the causes we have mentioned.

A third possibility, and one which cannot be dismissed lightly, is that this failure is due to statistical treatment of the Ss in groups, when in the other experiments the results of the Ss were considered individually. One could assume that

various individuals among our Ss perceived the figures in different ways, and that they could therefore be expected to show memory changes in different directions. A balancing of directions and amounts of change might conceivably be produced in this way. Against such an interpretation is the irregularity of the changes. In seven cases (curves 1, 2, 5, 6, 7, 8, 11) the curves of Fig. II move in one direction from 3 min. to 10 min., and in the opposite direction from 10 min. to 7 days. The statistical reliability of the changes of direction of these curves is difficult to estimate. Since the homogeneity of the populations involved is suspect, we should not like to rely upon simple measures, nor do we wish to over-statisticize the data. It is possible, then, to consider the irregularities to be the result of a high degree of variability, in which case they cannot be held against the 'balancing' effect suggested above. But if progressive increases in asymmetry are covertly present in the results, it is then necessary to assume, first, that just the right amounts of change in opposite directions to produce approximate balancing existed in each group of judgments, and second, that the balancing itself has been obscured by variability. We consider it more reasonable to accept the results at something nearer their face value, and to conclude that progressive changes are not present.

The definite and consistent asymmetries must still be explained. In discussing them above we have had to refrain from offering them as crucial to available theories, although in some instances they appear favorable to Gestalt theory. Aside from the question of immediate explanation, it may be pointed out that nothing seems to prevent one's calling the asymmetries 'time-errors,' and thereby recognizing the probable fundamental identity of the problems of the time-error and of memory changes, which have been in the past too frequently divorced from each other. We see no good reason why one man should be an expert on the time-error and another on memory changes. This is not to overlook the psychological differences of judging, remembering, reproducing and recognizing. But the search for processes underlying all of these activities can be rich in suggestions for

experiment and must eventually lead to more powerful and comprehensive theories. Professor Koffka's trace theory is an example of the success that can attend such an effort, whether or not one likes trace theories in general or this one in particular. Such a broad theory would not have been possible had Koffka not been bold enough to see beyond the superficial and mechanical differences which often obscure more fundamental likenesses. The method and results of this experiment may be of use in helping to remove non-essential boundaries that have been set between the domains of the time-error and memory changes.

Summary

Six simple figures were exposed visually to groups of Ss, who made judgments on 11 characteristics of the figures 3 min., 10 min. and 7 days after the first exposures. Definite asymmetries of the judgment distributions were found; these asymmetries showed a high degree of consistency at the three time intervals. No general tendency toward progressive increase in asymmetry was found. Results which can be interpreted under the laws of Prägnanz and closure were obtained in the case of three of the eleven characteristics; for the other eight the results were inconclusive in the absence of further knowledge. The methods of comparison and reproduction are discussed, with indications of some advantages of the former. The probable basic identity of the problems of the time-error and memory changes is suggested.

(Manuscript received April 22, 1937)

AN EXAMINATION OF THE COMPUTING ABILITY OF MR. SALO FINKELSTEIN

A. Administration, Description of the Tests, and General Psychological Conclusions

BY JAMES D. WEINLAND

B. Statistical Analysis of the Correlation Between Number of Separate Acts of Attention in Tests, with Time Required, as Well as with Accuracy of Performance

BY W. S. SCHLAUCH

I. Character and Background of the Subject

Salo Finkelstein, Jewish, 35 years old, born in Lodz, Russia, now Poland, and carrying references proclaiming him a 'lightning calculator' to be compared with Dr. Ruckle, Inaudi or Diamondi, presented himself at the laboratory of New York University, School of Commerce, and offered to subject his calculating ability to examination and test.

He gave the following information: As a boy in school he did his number work more quickly than the average student, and liked arithmetic better than history or geography, but he had no premonition of the calculating ability which he was later to discover in himself. When he was 23 years old, and out of school, a friend of his claimed that he could multiply mentally two numbers of three digits each. F. tried it and found he could do even better. He easily multiplied in his head two numbers of six digits each! F. analyzed the process and found that to multiply numbers by memory, it is not necessary to be a good calculator, but it is necessary to have a good visual imagery to keep the numbers in mind. He tried to repeat both acoustically and visually presented numbers. He did it well and began demonstrating for the public. He lost interest however and gave up the practice till his 27th year when he read a newspaper account of a man with a good

memory for numbers. He recalled his own success of the previous years and tried again. This time he gave demonstrations to which medical men, teachers, scientists and the newspapers were invited. He tried to do things never before attempted and did them without mistake. Soon after this he was employed in the State Statistical office of the Polish Government. He frequently was assigned to the treasury department on special problems where especially quick and exact work was necessary. In calculating budgets, sums must be combined in various ways, and the results known quickly. This he did for the treasury. He worked for the government for 11 years and in that time not a single error was found in any of his calculations. The explanation of this is that he always checked his work, doing the problem in some other way than at first. It is his custom still to check each calculation he makes and in his public performances he usually follows his statement of the answer with the words, "check . . . no mistake." If any mistake is found after he gives the signal, F. has made the standing offer that he will pay $100 to have it pointed out.

In 1928, F. was invited by Professor Hans Henning in Danzig for a test. As Prof. Henning had previously tested Ferroll and Ruckle he could make a comparison. He found F. a superior calculator but was most interested in the associations he found with numbers. F. had an æsthetic feeling in regard to numbers. He felt in them a beauty comparable to music or art. In 1930, at the age of 33 F. was invited to the international convention of insurance mathematicians in Stockholm. This group confirmed the previous judgments that his abilities were marvelous. In 1931 F. gave up his position with the government to go around the world to demonstrate his abilities and submit to scientific tests. He was tested by Bela Sandor in the Institute of Industrial Psychotechnics in the Technical Highschool in Berlin. This investigation is reported in *Character*, 1, 1932, page 47. Sandor found his memory for letters average, his memory for drawing below average. In the United States F. demonstrated in a number of universities. For a period covering

several months F. came frequently to the School of Commerce, New York University, and submitted to the tests in calculation presented here. He did not wish to take an intelligence test. His calculating abilities speak for themselves.

II. The Subject's Attitude Toward His Own Ability

F. can analyze and give some insight into his own mental processes. He has studied psychology, especially that relating to memory, and knows of the performance of the preceding lightning calculators. But with all his ability to manipulate numbers, F. is not a mathematician. By using his special abilities he is able to make calculations he believes of value to mathematicians and also to many others. For instance, concerning mathematical processes, he is able to reduce numbers to the sum of three or four squares very rapidly. Thus he reduced 9,413 to the sum of 95^2 plus 12^2 plus 12^2 plus 10^2 in ten seconds. No principle or law explaining how this can be done is known.

So far as we can observe, F. works merely by trial and error, but works so rapidly that it would be possible to gather a great amount of data concerning his methods in a short time. General principles might possibly be derived if we had more detailed and elaborate data on his methodology.

III. The Tests and the Data They Yielded

Various devices were used in the calculating tests. A pendulum chronoscope was connected with a balloptican, in such a way that time was measured as long as the figures were projected on the screen. F. threw the light on and snapped a switch in his hand, turning it off, as soon as he felt that he could answer the problem. The whipple statistoscope was used for some exposures. The calculating tests requiring more than four seconds were measured with a stop watch. A paper with a problem written on it was presented to F., or while his back was turned the problem was written on the blackboard. At the signal, beginning the time measurements, F. turned, made a line through the numbers and wrote down the result. Drawing the line seemed to help him, as though

"he was prodded with a stick." When he was trying to work very fast he would draw the line with more emphasis. In difficult experiments he has noticed the strain on his body. He says he has had a pulse of 140 in some performances. "I feel not so bad today because the artist in my personality defends me from it, and seeing my success counterbalances the weakness I experience during the performance." He reported that he feels the strain most when obliged to make experiments outside the field of numbers where his ability is 'above average but not phenomenal.' He showed a warming up curve with increasing concentration on each test day. He would work on his calculation for half a day at a time. He claimed he did not get tired. He said there was no work to it . . . but he would pace back and forth under high nervous tension. He showed slight distractibility and little fatigue. He believes concentration to be the dominating factor. He eliminates other things that might influence. In more difficult calculations, memory is the most important thing. It is important in recalling at the proper time the right associations and the right method of work to deal with the vast quantity of material in the mind. F. states that he never practices except in giving demonstrations. He claims that he discovered his ability and did not develop it. He has an active intense preference for complexes rather than for individual numbers. It worried him considerably if he made several mistakes in succession. He then would stop for the day. He explained that to work so very rapidly he had to have confidence. Anything that disturbed his confidence made it impossible to work. He claimed that he did not have eidetic imagery and stated in evidence of this that no matter how digits were presented to him, no sooner was the exposure ended than he saw the digits in his own handwriting. He is not dependent on mood or health. He can notice changes in these respects but others can't tell the difference. He believes his attention and concentration are always above the average; sometimes extraordinary. He could add or multiply much more rapidly than he could divide, and preferred these processes. Only once did he do a problem in division at New York University,

dividing mentally 67,916,288 by 8,558 and giving the correct answer in three minutes. He knows 300 decimals of Pi. He knows logarithms from 1–100 to 7 decimals. He knows logarithms from 100–150 to 5 decimals. This helps him in his calculations.

He remembers many hundreds of dates, but only when the matter is specially interesting or when the number is 'nice.' 0 for instance is not 'nice.' The nicest numbers are combinations that happen to please. A great many tests were given F. at N. Y. U. The results of a few of these tests are shown in Tables I–III.

TABLE I

TIME IN SECONDS OF HORIZONTAL AND VERTICAL ADDITION

Number of Columns	Number in Column	Total No. Digits	Addition Time in Seconds	
			Horizontal	Vertical
1	60	60	15.4	13.8
2	30	60	15.7	15.9
3	20	60	19.7	16.5
4	15	60	14.0	19.5
5	12	60	17.3	15.7
6	10	60	15.1	17.6
10	6	60	17.3	16.9

Methods: F. reports that simple numbers mean nothing to him. He likes them only when they are in complex form. His mental processes in adding the digits 9 7 4 3 8 7 5 9 8 7 4 he gave as follows: $9 + 7 + 4 + (3 + 7) + (8 + 5) + (7 + 4) + (9 + 8) = 71$. In his mental calculations F. does not use mnemonic methods. He does not reduce the numbers to factors. When he multiplies in memory or on the blackboard, he uses well known methods from commercial arithmetic. He made use of the distributive law, multiplying 58×43 in seven seconds as follows: $50 = \frac{1}{2}$ of 100. $\frac{1}{2} \times 43 = 21.5$, $\therefore 50 \times 43 = 2{,}150$. $8 \times 43 = 344$. $2{,}150 + 344 = 2{,}494$. By the factor method he multiplied 44×88, writing the answer at once. $44^2 = 1{,}936$. $88 = 2 \times 44$. $1{,}936 \times 2 = 3{,}872$. By single factor multiplication he wrote the product of 77×33 immediately. $3 \times 77 = 231$ ($\times 10$) $+ 231 = 2{,}541$.

TABLE II

REDUCING TO SUM OF THREE SQUARES

Number	Result Reported†	Time (Seconds)
129	11–2–2	2.0
99	9–3–3	1½
74	(8–3–1)—(7–4–3)	4½
67	7–3–3	(?)
53	6–4–1	5.0
45	5–4–2	7.0
37	(Cannot be done)	16.0
33	(4–4–1)—(5–3–2)	3.0
29	4–3–2	3¾
27	(5–1–1)—(3–3–3)	1½
25	(Cannot be done)	2.0
21	4–2–1	(?)
13	(Cannot be done)	(?)
10	(Cannot be done)	(?)
876	(26–10–10)—(26–14–2)	7.0
645	23–10–4	4.0
944	28–12–4	5.0
895	(Cannot be done)	1 minute
488	18–10–8	6.0
111	(Cannot be done)	(?)
832	(Cannot be done)	2 min. 10 sec.
472	20–6–6	1½
907	27–13–3	3.0
391	(Cannot be done)	(?)
395	15–13–1	3.0
*555	23–5–1	
101	9–4–2	1.0
186	13–4–1	7.0
487	(Cannot be done)	(?)
921	29–8–4	12.0
456	(Cannot be done)	(?)
876	26–14–2	7.0
579	23–7–1	8½
753	20–17–8	6.0
749	27–4–2	4.0
747	23–13–9	8¾
745	22–15–6	1 min. 56 sec.
743	(Cannot be done)	1 min.
741	23–14–4	6.0
425	20–14–3	1.0
427	15–11–9	1.0
133	9–6–4	(?)
131	11–3–1	1.0

* Note: Dissatisfied with first large number, tried to find numbers more nearly equal in size; couldn't.

† This column means, *e.g.*, $129 = 11^2 + 2^2 + 2^2$; $488 = 18^2 + 10^2 + 8^2$.

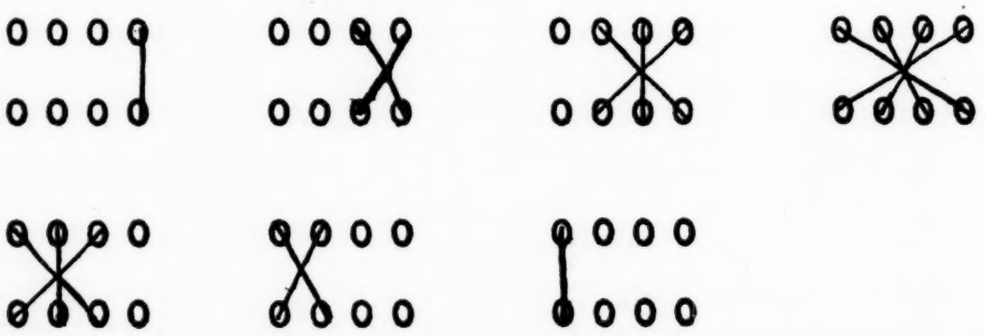
He used the cross product method a great deal. An example of the mental operations necessary to multiply a four place number by a four place number are as follows. In the mental

TABLE III
REDUCING TO SUM OF FOUR SQUARES

Number	Result Reported*	Time (Seconds)
863	27–11–3–2	60
1486	38–5–4–1	12
9625	95–22–10–4	6
1100	24–22–6–2	25
4444	62–22–10–4	15
6777	76–31–6–4	15
366	16–10–3–1	3.5
8123	81–39–5–4	50
4567	61–29–2–1	25
7889	81–36–4–4	30
753	24–13–2–2	26.5
6328	32–20–2–70	10
9413	95–12–12–10	10

* This column means, *e.g.*, $863 = 27^2 + 11^2 + 3^2 + 2^2$
$9413 = 95^2 + 12^2 + 12^2 + 10^2$.

multiplication all of these operations must be held in mind till the final answer is given.



By the use of this method F. multiplied 6,943 × 7,859 and gave the correct answer in 17.5 seconds.

F. stated that there is no known method of reducing numbers to the sum of squares. It must be done by trial and error. All numbers above a certain number can be reduced to the sum of four squares, but certain ones can not be reduced to the sum of three squares. Mental operations reported by F. in reducing certain numbers are as follows: Problem: reduce 6,328 to the sum of four squares. Thought that $71^2 = 5{,}041$. Thought of subtracting it; didn't like it, so didn't. Thought 72^2. Doesn't know it. $70^2 = 4{,}900$ subtracted from 6,328 = 1,428. Has it. 1,428 into 3 squares equals $32^2 + 20^2 + 2^2$, $\therefore$ $6{,}328 = 70^2 + 32^2 + 20^2 + 2^2$. Problem: reduce 9,413 to 4 squares. Took 91^2, it is 8,281. Subtracted from

9,413, result is 1,132. Subtracted 30^2, result is 232. 232 into two; $144 = 12^2$; not good; $32^2 = 1{,}024$; subtract from 1,132 = 108. Rejects this also since he can't reduce this to two squares. Threw 91 away; took $95^2 = 9{,}025$. Subtracted, 388. Thought of $324 = 18^2$; not good. Took $16^2 = 256$. $388 - 256 = 132$; not good. $388 = 2 \times 144 + 100$. Answer $95^2 + 12^2 + 12^2 + 10^2$.

Time: Ten seconds for each of the above problems, both done mentally.

IV. General Conclusions Drawn from the Testing Process

(*A*) Though F. calculates much more rapidly than the average person, his thinking processes are responsive to the same mental laws. His own idea that practice has no effect does not seem to be substantiated. This is evident from his work in division. He seldom demonstrates in division, has little practice in it, finds it somewhat difficult, and is comparatively slow. F.'s learning of numerical facts and associations has been very rapid, but it is nevertheless learning of the usual kind. His 'lightning calculations' all require time for their performance. Problems solved 'immediately' were not solved but recognized. F. had previously worked them and remembered the result. The fact that the solution-time is so often very short is an indication of skill and native quickness, not of any unnatural powers.

(*B*) Concentration, memory, and confidence are among the most necessary mental qualities for this kind of work.

(*C*) The fact that F. added horizontally, with little practice, as rapidly as vertically after much practice, is significant. He required much less practice in horizontal addition. The speed may have indicated transfer of skill from the eye movements of reading, or it may be due to the wider span of horizontal than of vertical perception. With equal practice horizontal addition should be faster than vertical addition. The results indicate that, disturbing conventional accounting and bookkeeping systems aside, the speed of addition for people in general might be increased by teaching horizontal rather than vertical addition.

B. Statistical Analysis of the Data

BY

W. S. Schlauch

The general psychological conclusion that even in the case of a computing prodigy, time is required to complete an addition or a multiplication naturally raises the questions, "How much time is consumed?" and "Does the time consumed vary in any regular way with measurable elements of the computation problems solved?" The tests show that in the case of addition, the time needed to add depends on the number of digits added, and is not appreciably affected by the number of columns into which the digits are arranged. In multiplying numbers of varying numbers of digits, the evidence indicates that the time varies *not* with the number of digits, but with the separate acts of attention involved in the process, which rapidly increases as the number of digits is increased.

The last statement is true also of addition, as the number of acts of attention here varies with the number of digits. So that in computation, whether addition or multiplication, the correlation seems to be between *number of separate acts of attention* and *time taken*, and also between *number of separate acts of attention* and *accuracy of the result.*

It is important to know, not only that the time taken *increases* as the number of acts of attention involved increases, but also the *law* of increase or variation. Is the increase of time needed in *proportion* to the number of acts of attention, or does it vary as the *square* of the number of separate acts of attention? These questions can be answered, provided the data are adequate, by a statistical analysis. We proceed, therefore, to a study of the correlation problems involved in these experimental data.

V. Correlation of Time Consumed in Addition, with Number of Digits to be Added

In adding a column of digits there is a separate act of attention for every digit added to the sum of the digits pre-

viously united. (Thus the span of attention is widened approximately in proportion to the number of digits to be united.) The number of columns of digits also enters into the problems slightly as, for example, 24 digits in one column involve 24 acts of summation of each succeeding digit with the units digit of the previous sum and the corresponding 'carry.' If the 24 digits are in *two* columns we have the same number of 'unite' and 'carry' acts, but there is a break in registering the units digit of the sum of the first column before continuing with the second column. There is also the shift after the addition in the second column of again considering the digits of this result as *units* of the next higher order. There would thus be 25 acts of conscious manipulation involving attention. However, this element disturbs our results only slightly, as may be seen from the graph showing the relation of time in seconds to accomplish horizontal and vertical addition to the number of digits added.

The moving average of the time for vertical addition is also shown on the graph. It follows a straight line trend so closely that we are justified in finding linear correlation of these elements.

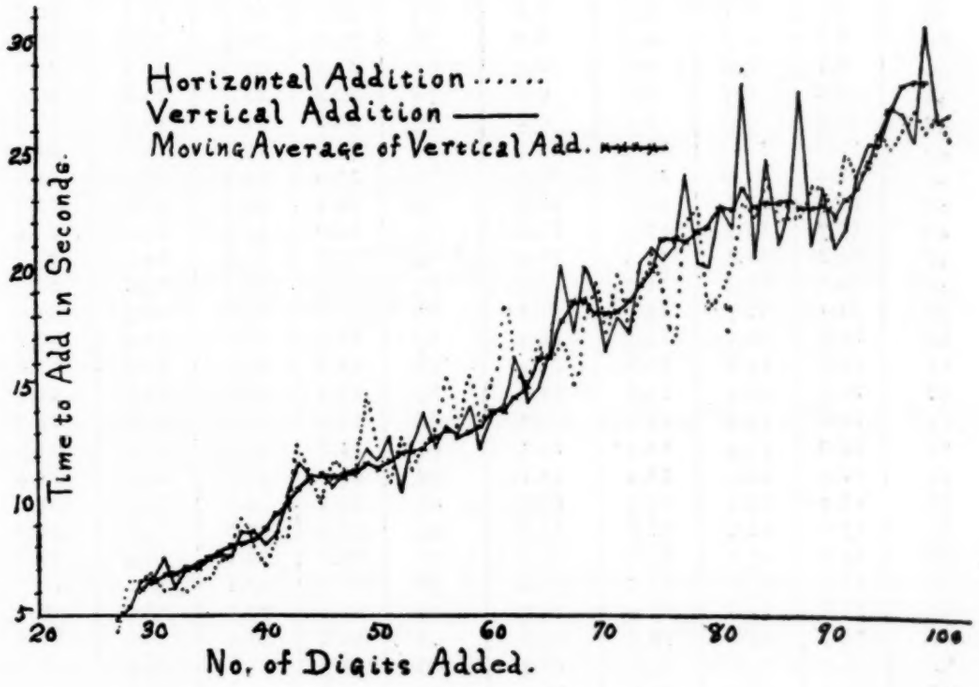


FIG. 1. Graph of time to add, in seconds.

Correlation of Time to Add with Number of Digits Added in Vertical Addition

Using the data of Table IV we may derive the equation of the regression line of *time to add* on *number of digits added*, by using the individual items. For this purpose we set up a table in which the items in the column 'Number of Digits' are called X, those in the column headed 'Observed Time' are

TABLE IV

FINKELSTEIN TESTS

Time in Seconds for Vertical and Horizontal Addition

No. of Digits	Vertical Adding Time		Horizontal Adding Time		No. of Digits	Vertical Adding Time		Horizontal Adding Time	
	Observed	Moving Average	Observed	Moving Average		Observed	Moving Average	Observed	Moving Average
27	4.8		4.3		64	15.0	16.3	17.0	16.1
28	5.4		6.5		65	16.4	16.4	15.6	16.0
29	6.5	6.2	6.5	6.0	66	20.2	17.8	16.8	16.6
30	6.7	6.5	6.7	6.4	67	17.3	18.6	15.2	17.1
31	7.5	6.8	6.1	6.3	68	20.2	18.7	18.5	17.5
32	6.2	6.9	6.2	6.2	69	19.0	18.2	19.5	18.1
33	7.0	7.1	6.0	6.2	70	16.6	18.2	17.4	18.5
34	7.3	7.1	6.0	6.5	71	18.0	18.3	19.8	18.6
35	7.5	7.4	6.7	6.8	72	17.4	18.7	17.5	18.8
36	7.6	7.7	7.7	7.4	73	20.3	19.4	18.8	19.2
37	7.6	8.0	7.5	7.9	74	21.0	20.0	20.8	18.6
38	8.7	8.1	9.3	8.0	75	20.5	21.4	19.1	19.6
39	8.7	8.3	8.5	8.2	76	21.0	21.4	17.0	20.4
40	8.1	8.9	7.2	8.4	77	24.3	21.3	22.2	19.9
41	8.6	9.5	8.5	9.1	78	20.4	21.7	22.8	19.9
42	10.3	9.9	8.5	9.5	79	20.2	21.9	18.4	20.5
43	11.6	10.6	12.5	10.1	80	22.8	22.7	19.0	21.7
44	11.2	11.0	10.8	10.7	81	21.9	22.7	20.4	21.6
45	11.2	11.2	10.0	11.3	82	28.2	23.7	28.0	22.8
46	10.7	11.1	11.7	11.0	83	20.6	23.4	22.4	23.4
47	11.2	11.1	11.4	11.9	84	24.9	23.5	24.2	23.8
48	11.3	11.3	11.2	12.3	85	21.2	23.5	22.2	22.7
49	12.4	11.7	14.9	12.1	86	22.8	23.6	22.3	23.0
50	11.8	11.5	12.0	12.4	87	27.9	23.3	22.4	22.8
51	12.8	11.8	10.8	12.4	88	21.1	23.3	23.8	22.8
52	10.5	12.1	12.8	11.9	89	23.5	23.1	23.6	23.4
53	12.6	12.2	11.5	12.2	90	21.0	22.3	22.2	23.7
54	14.0	12.4	12.5	13.1	91	21.8	23.2	25.0	23.9
55	12.4	12.9	13.2	13.1	92	24.2	23.6	24.2	24.4
56	13.4	13.2	15.5	13.9	93	25.5	24.8	24.6	25.0
57	13.0	12.9	12.8	14.0	94	25.5	25.8	25.8	25.3
58	14.2	13.1	15.5	14.5	95	27.1	26.1	25.4	25.8
59	12.4	13.3	13.0	15.1	96	26.9	27.1	26.2	26.1
60	13.8	14.0	15.4	15.7	97	25.6	27.3	27.0	26.3
61	14.3	14.0	18.5	15.6	98	30.6	27.3	26.0	26.3
62	16.4	14.6	15.8	16.4	99	26.5		26.8	
63	14.4	15.1	15.2	16.4	100	26.7		25.6	

called Y. The column headings of the table are then: X, Y, X^2XY, and Y^2. The totals of these columns are respectively:

4665, 1201.0, 330 993, 86 939.5, and 23 112.92.

The table itself is omitted to save space. From these totals we find:

$$M_x = \frac{4665}{73} = 63.904, \qquad M_y = \frac{1201}{73} = 16.452.$$

For the equation of the regression line, $Y' = a + bX$,

$$b = \frac{\Sigma XY - nM_xM_y}{\Sigma X^2 - nM_x^2} = \frac{86939.5 - 73 \times 63.904 \times 16.452}{330\,993 - 73 \times 63.904^2} = .31,$$

$$a = M_y - bM_x = 16.452 - .3099 \times 63.904 = -3.35.$$

The regression equation is:

$$Y' = -3.35 + .31X,$$

where Y' is the most probable time in seconds to add, and X is the number of digits added. Thus, if we wish to find the most probable time necessary to add 80 digits,

$$Y' = -3.35 + .31 \times 80 = 21.45 \text{ seconds.}$$

The experiments showed actual time taken was 22.8 seconds. The coefficient of correlation is given by

$$r = \frac{\Sigma XY - nM_xM_y}{\sqrt{[\Sigma X^2 - nM_x^2][\Sigma Y^2 - nM_y^2]}} = \frac{10\,191.0}{\sqrt{32\,881.4 \times 3354.1}} = .972.$$

If we adjust for number of samples, calling the adjusted coefficient r, we find

$$\bar{r} = .968.$$

The high coefficient of correlation indicates that a very close estimate of the time it will take this prodigy to add a given number of digits can be made by using the regression equation. To measure *how* accurate the estimate is, we pro-

ceed to find the *standard error of the estimate*. For this purpose, a column of values of Y', corresponding to each given X of the experiment, was calculated; then a column of values of $Y - Y'$ (or Z), and a column of values of Z^2.

The Z^2 column total is 190.71.

The unadjusted standard error is

$$S = \frac{Z}{n - 1} = \frac{190.7}{72} = 2.64875,$$

from which $S = 1.62$ sec.

The adjusted standard error is

$$\bar{S} = 1.64 \text{ sec.}$$

This means that there is about a 2 to 1 chance that the actual time taken in such an addition problem will not differ from the estimated time by more than 1.6 seconds.

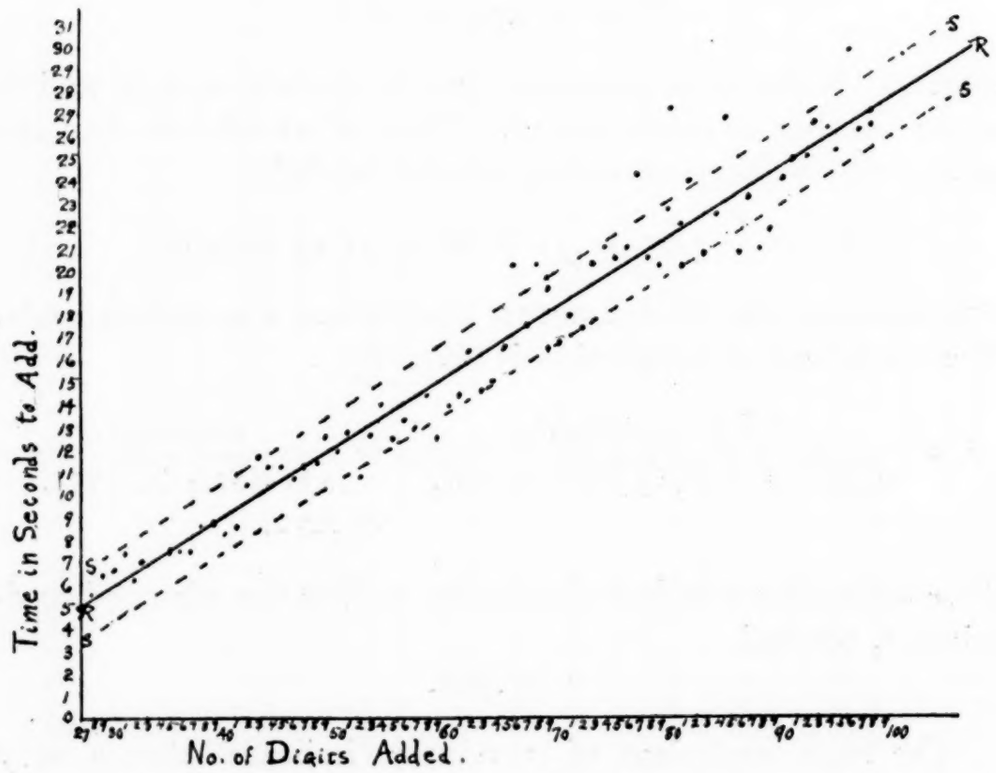


FIG. 2. Correlation of vertical addition time with number of digits added.

These facts are illustrated in the following graph, Fig. 2. *RR* is the regression line, and the dotted lines *SS* are the limits of the standard error of the estimate.

The rather wide fluctuation of the time required for the addition when the number of digits exceeded 80 makes S wider than would be the case, if the standard error had been calculated from the specimens whose number of digits ranged from 27 to 76.

The conclusion seems safe that the time needed for executing the mental processes involved in adding digits is a *linear* function of the number of digits added.

It also appears that for this individual at least, residual factors such as a feeling for certain digits, or other like elements, play a small part in the process. The memory factor, as well, requires no more time as the number of digits increases.

VI. Statistical Interpretation of Multiplication Tests

In these tests, examples were given, covering the multiplication of two digits by two digits, three digits by three digits, four by four, and five by five. The number of separate acts of attention called for in these four classes of examples were respectively six, twelve, twenty-one, and thirty-two. The data are thus somewhat scanty from which to draw valid conclusions as to the regression line. If three digits by two digits, three by four, etc., had been included, we should have some basis for deciding whether the regression line is linear or follows a parabola of the type

$$y = ax^2 + bx + c.$$

Since the multiplying of one number by another involves not only a certain number of acts of attention which are easily accomplished because they have been previously routinized, but involves as well (and simultaneously) the mental arrange-

ment of partial results according to *order* of digits, as units, tens, etc. and then their summation as additional separate acts of attention, it may well be that the regression is actually a curved line. Certainly the second degree parabola would fit the data with a smaller standard error than the straight line does. Additional tests must be made to determine the real nature of this regression curve. The straight line regression affords a good estimate of the time needed by Mr. Finkelstein for mentally multiplying numbers up to five digits by five digits.

If we average the time needed to complete each of the four types of example used in the multiplication test, and find the percent of each type solved correctly we have:

TABLE V

AVERAGE TIME AND ACCURACY IN MULTIPLICATION

Type of Example 1	Range of Time to Complete (Seconds) 2	No. of Examples 3	Average Time for Type (Seconds) 4	Percent Correct 5
2 by 2 (6 acts)	2.0–14.0	30	4.03	93.3
3 by 3 (12 acts)	5.5– 5.6	6	5.7	83.3
4 by 4 (21 acts)	12.0–18.5	10	13.5	60.0
5 by 5 (32 acts)	19.2–28.6	9	25.8	44.4

Plotting columns 1 and 4 shows positive correlation, while columns 1 and 5 show decided negative correlation. The linearity of the first is in doubt, but that of the second is not doubtful, so far as these four types are concerned.

Since the number of items is not great we use the separate items in finding the coefficient of correlation and the equation of the regression line. This, of course, gives a more accurate result than if a double entry table had been used. The details of the calculation can be understood by inspecting the following table and the formulæ following it.

TABLE VI

1	2	3	4	5	6	7	8	9	10	11
No. Acts of Attention X	Time in Seconds Y	F	FX	FY	FX^2	FY^2	FXY	Y'	$Z = Y - Y'$	FZ^2
6	2.0	1	6	2.0	36	4.00	12.0	3.4	− 1.4	1.96
6	7.0	1	6	7.0	36	49.00	42.0	3.4	+ 3.6	12.96
6	4.0	1	6	4.0	36	16.00	24.0	3.4	+ .6	.36
6	9.0	1	6	9.0	36	81.00	54.0	3.4	+ 5.6	31.36
6	14.0	1	6	14.0	36	196.00	84.0	3.4	+10.6	112.36
6	1.0	4	24	4.0	144	4.00	24.0	3.4	− 2.4	23.04
6	3.5	3	18	10.5	108	36.75	63.0	3.4	+ .1	.03
6	4.7	4	24	18.8	144	88.36	112.8	3.4	+ 1.3	6.76
6	5.5	4	24	22.0	144	121.00	132.0	3.4	+ 2.1	17.64
6	2.8	5	30	14.0	180	39.20	84.0	3.4	− .6	1.80
6	3.1	5	30	15.5	180	48.05	93.0	3.4	− .3	.45
12	5.5	1	12	5.5	144	30.25	66.0	8.2	− 2.7	7.29
12	5.5	2	24	11.0	288	60.50	132.0	8.2	− 2.7	14.58
12	5.6	3	36	16.8	432	94.08	201.6	8.2	− 2.6	20.28
21	18.5	1	21	18.5	441	342.25	388.5	15.4	+ 3.1	9.61
21	12.0	1	21	12.0	441	144.00	252.0	15.4	− 3.4	11.56
21	17.5	1	21	17.5	441	306.25	367.5	15.4	+ 2.1	4.41
21	12.3	2	42	24.6	882	302.58	516.6	15.4	− 3.1	19.22
21	13.0	2	42	26.0	882	338.00	546.0	15.4	− 2.4	11.52
21	12.1	3	63	36.3	1,323	439.23	762.3	15.4	− 3.3	32.67
32	19.2	1	32	19.2	1,024	368.64	614.4	24.2	− 5.0	25.00
32	26.3	2	64	52.6	2,048	1,383.38	1,683.2	24.2	+ 2.1	8.82
32	28.6	2	64	57.2	2,048	1,635.92	1,830.4	24.2	+ 4.4	38.72
32	25.8	2	64	51.6	2,048	1,331.28	1,651.2	24.2	+ 1.6	5.12
32	26.0	2	64	52.0	2,048	1,352.00	1,664.0	24.2	+ 1.8	6.48
		55	750	521.6	15,570	8,811.72	11,400.5			424.00

$$M_x = \frac{750}{55} = 13.636, \qquad M_y = \frac{521.6}{55} = 9.484.$$

For Regression line $Y' = a + bx$,

$$b = \frac{\Sigma XY - nM_xM_y}{\Sigma(X^2) - nM_x^2} = \frac{11400.5 - 55 \times 13.636 \times 9.484}{15570 - 55 \times 13.636^2}$$
$$= .8024,$$

$$a = M_y - bM_x = 9.484 - .8024 \times 13.636 = - 1.458.$$

The Regression Equation is: $Y' = - 1.458 + .802X$,
where X = No. acts of attention involved in problem,
Y' = No. seconds required to solve on the average.

For the Coefficient of Correlation:

$$r = \frac{\Sigma XY - nM_xM_y}{\sqrt{[\Sigma(x^2) - n(M_x)^2][\Sigma(Y^2) - n(M_y)^2]}},$$

$$\therefore r = \frac{4287.69}{5343.27 \times 4947.04} = \frac{4287.69}{5138.93} = .8344.$$

If we adjust r for the number of samples, $\bar{r}$ being the adjusted coefficient, as r is the unadjusted coefficient, we have:

$$\bar{r} = .831.$$

We may thus estimate the time in seconds it will take this prodigy to find the result in multiplying, up to 5 digits by 5 digits by the equation

$$Y' = -1.458 + .802X,$$

and most of the variation of time required is accounted for by the number of separate acts of attention involved in the multiplication of the separate digits and the addition of the partial results.

To find the standard error of the estimate made from this regression line we find Y' for $X = 6$, 12, etc., and find the residuals of the separate trials.

If $X = 6$, $Y' = -1.458 + 4.812 = 3.354$.
$X = 12$, $Y' = -1.458 + 9.624 = 8.166$.
$X = 21$, $Y' = -1.458 + 16.842 = 15.384$.
$X = 32$, $Y' = -1.458 + 25.664 = 24.206$.

These values, given by the regression equation, fall between the actual averages. We use these values in columns 9, 10 and 11.

The unadjusted Standard Error of the Estimate (made by our regression line), is

$$S_{yx}^2 = \frac{Z^2}{n-1} = \frac{424.00}{54} = 7.8518,$$

$$\therefore S_{yx} = 2.80 \text{ sec. or } 2.8 \text{ prac.}$$

For the adjusted Standard Error:

$$\bar{S}_{yx} = 2.83 \quad \text{or} \quad 2.8 \text{ practically.}$$

This means that if we estimate the time it will take Mr. Finkelstein to finish a problem in multiplication of the above type from the number of acts of attention involved in the problem, and repeat this a considerable number of times, approximately 68 percent of the actual times would not differ from their corresponding estimated times by more than 2.8 seconds.

On the accompanying graph, the Regression line is shown, and a band on either side, 2.8 seconds wide, limited by the dotted lines, shows the region within which 68 percent of the estimates will fall.

The separate black dots (.) on the diagram show the actual time records of the test. The open circles (o) show the average of the trials in which six acts of attention, 12 such acts, etc., were involved.

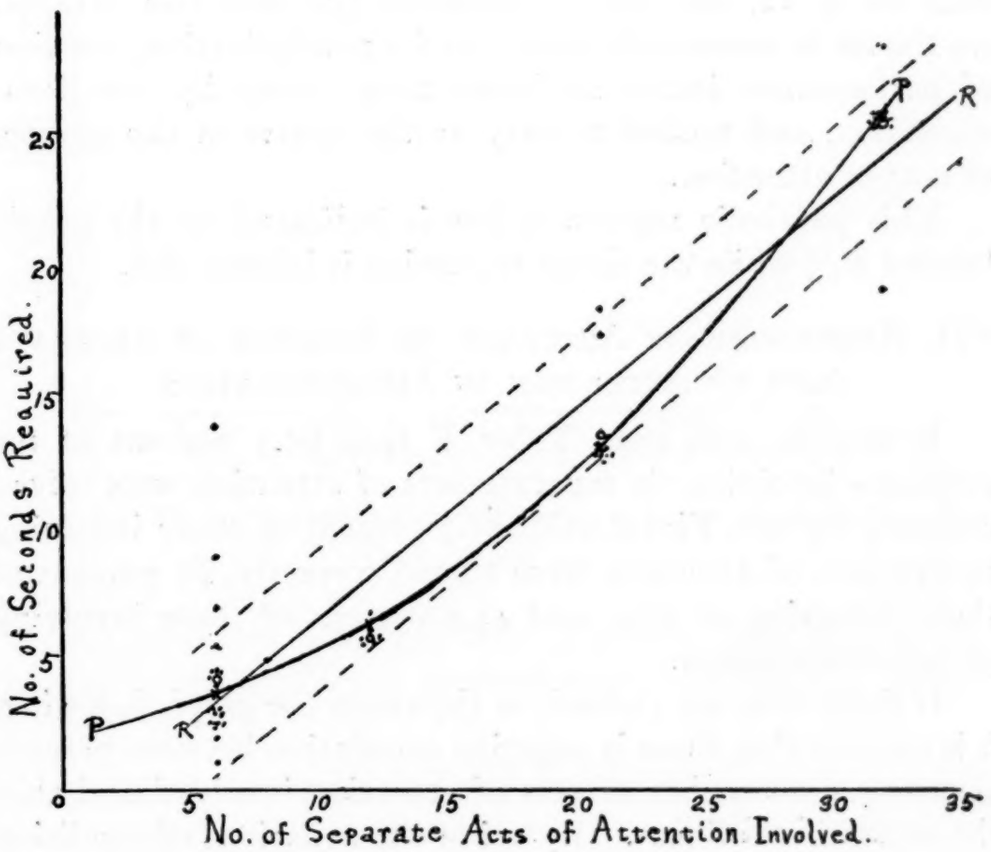


FIG. 3. Correlation of time required with number of separate acts of attention in multiplication.

Probable Curved Regression Line for Time Required in Multiplying

If we use the method of least squares to fit a second degree parabola to the average data:

No. Acts of Attention (X)	Time to Complete (Y)
6	4.03
12	5.70
21	13.50
32	25.80

we find that the equation is:

$$Y' = .0212X^2 + .0473X + 2.6994.$$

The calculated values for Y (Y') for $X = 6, 12, 21, 32$ respectively are:

3.75, 6.32, 13.04, 25.92.

This, of course, is a better fit than the straight line, and would greatly reduce the standard error of the estimate. If the data for 9, 12, etc. acts of attention fell near this parabola we should be reasonably sure that for multiplication, the time of performance increased faster than shown by the linear regression, and tended to vary as the square of the number of acts of attention.

This parabolic regression line is indicated on the graph, labeled *PP*, while the linear regression is labeled *RR*.

VII. Regression of Accuracy on Number of Separate Acts of Attention in Multiplication

It may be seen from Table V that 93.3 percent of the problems involving six separate acts of attention were solved correctly by Mr. Finkelstein; 83.3 percent of those involving twelve acts of attention were solved correctly, 60 percent of those involving 21 acts, and 44.4 percent of those involving 32 acts of attention.

If these data are plotted, as shown on the graph following, it is evident that there is negative correlation between percent accurate and number of acts of attention involved and that the regression is linear. By using the equations of condition

$$a\Sigma x^2 + b\Sigma x = \Sigma xy,$$
$$a\Sigma x + bn = \Sigma y,$$

we find the coefficients a and b of the regression line

$$y = ax + b.$$

Substituting the values of Σx^2, Σx, Σxy etc. (where x is the number of acts of attention, and y the percent accurate),

$$1645a + 71b = 3886.5,$$
$$71a + 4b = 269.9.$$

Solving,

$$a = -2.35,$$
$$b = 109.19.$$

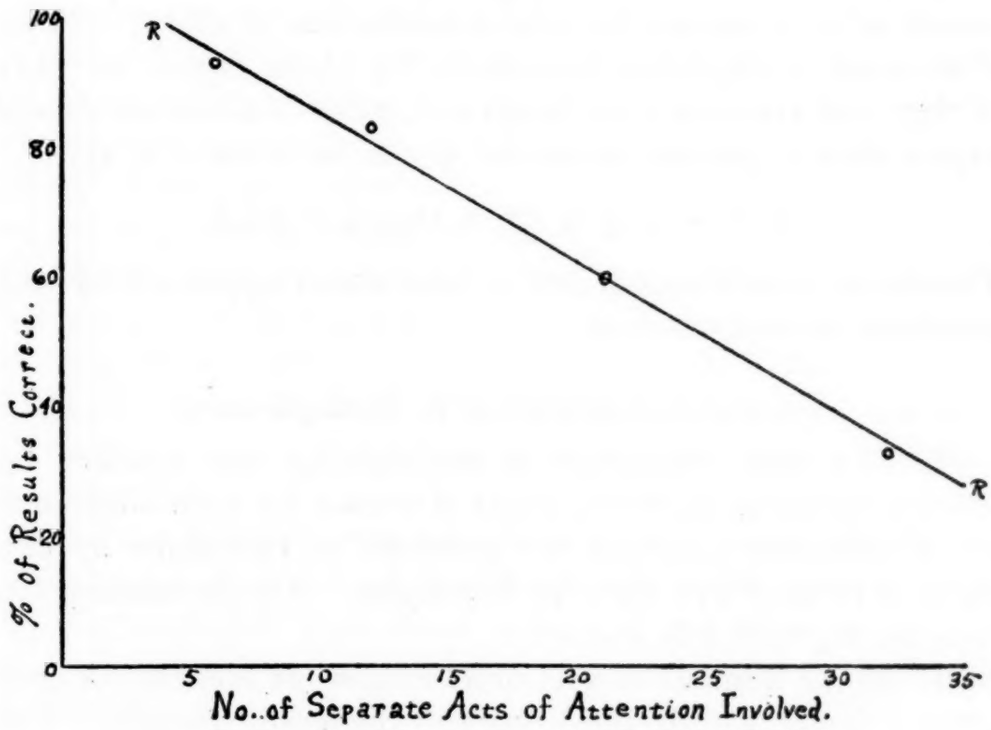


FIG. 4. Regression of accuracy on no. of acts of attention.
$y = -2.35x + 109.19$.

The equation, showing how accuracy declines, on the average as the number of separate steps of attention increases is thus

$$y = -2.35x + 109.19.$$

To test the accuracy of fit of this line, we find calculated average values of y, to compare with the observed average values.

	(Calc. y)	(Obs. y)	(Devia.)
If $x = 6$,	$y = 95.1$	93.3	+ 1.8
$x = 12$,	$y = 81.0$	83.3	− 2.3
$x = 21$,	$y = 59.8$	60.0	− 0.2
$x = 32$,	$y = 34.0$	33.3	+ .7

It may be seen that the sum of the deviations of the observed average accuracy percents from the calculated values is zero.

If our regression line equation gives the correct formulation of the relation involved, we should be able to calculate within very narrow limits of error the percent of problems this prodigy would solve correctly for any combination of digits. Thus, if he tried multiplying four digits by three digits, as 7,345 × 639, and tried such problems a number of times we should expect that y (percent accurate) would be, since $x = 17$,

$$y = -2.35 \times 17 + 109.19 = 69.2.$$

That is, we should expect him to have about 69 percent of such problems correctly solved.

General Conclusions as to Multiplication

1. The time consumed in multiplying one number by another mentally increases about .8 second for each additional act of attention involved, for problems of two digits by two digits to those of five digits by five digits. (On the assumption that the regression is linear.)

2. As the number of acts of attention (or mental manipulations) is increased, the accuracy decreases rapidly. The decrease in percent of accuracy is 2.35 percent for each additional act of attention involved in the Example, on the average.

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AN ATTEMPT AT CREATING SENSORY CONDITIONED REFLEXES IN HUMANS

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The work described in the present paper originated in the following way: for a certain time we have been making observations concerning the changes in the curve of electrical sensitivity of a dark adapted eye which appear when a light stimulation is applied to the other eye. For several days the experiment was daily repeated under exactly similar conditions. The light stimulation (brightness 250 luxes upon white) was always applied to the right eye after 50 min. of a binocular dark adaptation. The fact of a considerable heightening of electrical sensitivity under such conditions was already established in our joint work with S. V. Kravkov and E. N. Semenovskaya (**7**); this heightening occurred not only in the eye subjected to the light stimulation but in the other eye as well.

In the present experiments we shall speak of such a heightening of electrical sensitivity due to the action as the light stimulation took place as usual; but soon we noticed that a perceptible heightening of electrical sensitivity could be demonstrated in both eyes not only after the light stimulation but also several minutes before its beginning.

This fact contradicts everything we know about the changes of the electrical sensitivity in the course of the dark adaptation. The works of Achelis and Merkulov (**2**), Bogoslovski (**4, 5**), Schick (**15**) and others make it clear that the electrical sensitivity reaches its minimum after 15–20 min. of dark adaptation, then remains at this level (or even continues to sink a little) during the rest of time passed in darkness.

It seemed improbable that the phenomenon now observed by us could be attributed to any accidental fluctuations of

sensitivity; measurements taken on trained observers attained in our experiments after 10–15 min. of dark adaptation a high degree of precision so that they could be arranged into a straight line without any marked deviation. Moreover, both observers manifested the same phenomenon; this also speaks against the supposition of its being accidental.

Seeking for an explanation we came upon the following statement of I. P. Pavlov: "At the present time conditioning—a phenomenon implying in every case the activity of the highest nervous centers—can be extended to explain a number of biological processes; we know already that there exists conditioned leucocythosis, conditioned immunity and other conditioned organic processes."

This led us to the assumption that the spontaneous heightening of electrical sensitivity occuring always at the same minute of the dark adaptation at which in previous experiments the light stimulation was being applied, could be also considered as a sort of conditioned reaction. To determine the validity of this hypothesis we undertook a more detailed investigation of the phenomenon observed.

I. Technique of the Experiment

A brief description of the technique of measuring absolute thresholds of electrical sensitivity had been already given in our previous works (4), (5), (6), so that here only a short explanation will be given.

A storage battery of 4 v. served as source of current. The intensity of the current was regulated by a potentiometer.

Measurements were made by means of a spring galvanometer which permitted to define the intensity of the current passing through the eye with a precision of $1{,}3 \cdot 10^{-6}$ ampere.

Small silver tubes served as electrodes; one was soldered into a glass cup (electrode applied to the eye). Both tubes were filled with wet cotton. At the moment of measuring the threshold the first electrode was applied to the eye, the second put upon one of the fingers of the observer. The excitation was provided by closing the circuit 3 times in rhythmical succession.

The experiment took place in a room with blackened walls where the observer remained during 45–50 min. previously to the beginning of the experiment in order to become adapted to a feeble light (about 3–4 luxes). This feeble illumination lasted throughout the whole experiment but was always put out at the moment when measurements were being taken which means that in both eyes absolute thresholds of electrical sensitivity were measured. All the observers who took part in the experiments were carefully trained before.

II. Results

1. The heightening of electrical sensitivity in a dark adapted eye occurring at a definite minute of the adaptation, namely the same at which a light stimulation was usually given—is a time conditioned reflex.

Two observers took part in the experiments with a light stimulation. After several days of such experiments both observers—one after 10 days, the other after 7 days—began to manifest a spontaneous heightening of electrical sensitivity at about the same moment of the adaptation at which the light stimulation was usually given, *i.e.* on the 50th minute. Then without any warning we ceased to apply the light stimulation and for the next few days the experiment went on along the same lines as before but *without* light stimulation.

We can see from Table 1 that even under such conditions a considerable and quite definite heightening of electrical sensitivity occurred at the same moment at which on previous experiments the light stimulation was usually applied; after a few minutes the electrical sensitivity began to sink again and sank steadily until it reached its initial level.

After a few days during which no light stimulation was given, a perceptible decrease of this newly acquired individual reaction could be noted. Observer P. showed an obliteration of this spontaneous heightening of sensitivity somewhat earlier than observer S., namely after 5 days of experiments without light stimulation, while with observer S. a lapse of 6 days was necessary. After this time in both cases no heightening of electrical sensitivity at the 40–60th minute of dark adaptation

TABLE 1 *

CREATION OF A CONDITIONED HEIGHTENING OF THE ELECTRICAL SENSITIVITY OF THE EYE ON THE 50TH MINUTE OF THE DARK ADAPTATION.—SUMMARY OF RESULTS

Date	Time Elapsed from the Beginning of the Dark Adaptation															
	1′	10′	20′	25′	30′	35′	40′	45′	50′	53′	55′	60′	65′	70′	75′	80′	85′
	Observer P., 34 years of age																
7/IX 1935	171	140	115	—	—	113	—	—	113	—	—	113	—	113	—		
	175	137	119	—	—	113	—	—	113	—	—	113	—	113	—		
	DARKNESS																
9/IX	171	125	125	—	—	—	—	119	—	—	—	140	129	113	—		
	171	125	119	—	—	—	—	115	—	—	—	149	111	125	—		
	DARKNESS						LIGHT STIMULATION							DARKNESS			
11/IX	171	117	117	—	—	—	—	117	—	—	—	175	149	125	115		
	171	115	117	—	—	—	—	115	—	—	—	160	149	127	125		
	DARKNESS						LIGHT STIMULATION							DARKNESS			
13/IX	171	119	—	113	—	—	—	113	—	—	—	163	—	132	—		
	167	117	—	113	—	—	—	115	—	—	—	149	—	129	—		
	DARKNESS						LIGHT STIMULATION							DARKNESS			
14/IX	167	113	113	—	—	—	—	113	—	—	—	175	—	132	—		
	167	111	113	—	—	—	—	113	—	—	—	160	—	132	—		
	DARKNESS						LIGHT STIMULATION							DARKNESS			
15/IX	163	115	—	109	—	—	—	—	109	—	—	—	181	—	117		
	163	113	—	109	—	—	—	—	109	—	—	—	160	—	127		
	DARKNESS						LIGHT STIMULATION							DARKNESS			
17/IX	221	149	149	—	—	153	—	—	149	—	—	—	181	—	179		
	214	149	149	—	—	153	—	—	151	—	—	—	181	—	179		
	DARKNESS						LIGHT STIMULATION							DARKNESS			
19/IX	167	125	117	—	113	—	—	113	—	—	—	163	—	160	—		
	167	125	113	—	113	—	—	113	—	—	—	163	—	160	—		
	DARKNESS						LIGHT STIMULATION							DARKNESS			
21/IX	198	125	119	—	125	—	—	—	119	—	—	—	181	—	175		
	198	125	119	—	125	—	—	—	119	—	—	—	181	—	179		
	DARKNESS						LIGHT STIMULATION							DARKNESS			
23/IX	171	115	115	—	115	—	—	—	113	—	—	—	181	142	125		
	171	115	115	—	115	—	—	—	113	—	—	—	167	171	149		
	DARKNESS						LIGHT STIMULATION							DARKNESS			
26/IX	171	122	—	119	—	—	—	—	127	—	—	203	—	203	—		
	171	122	—	119	—	—	—	—	127	—	—	203	—	203	—		
	DARKNESS						LIGHT STIMULATION							DARKNESS			
29/IX	181	122	—	—	122	—	—	125	—	132	—	137	—	129	—		
	181	125	—	—	125	—	—	125	—	132	—	137	—	129	—		
	DARKNESS																

TABLE 1 (*continued*)

Date	Time Elapsed from the Beginning of the Dark Adaptation															
	1′	10′	20′	25′	30′	35′	40′	45′	50′	53′	55′	60′	65′	70′	75′	80′	85′
	Observer P., 34 years of age																
2/X	181	117	—	—	—	117	—	119	—	—	—	137	—	119	—		
	181	117	—	—	—	117	—	119	—	—	—	137	—	119	—		
	DARKNESS																
3/X	171	119	—	—	—	119	—	—	119	—	—	132	—	135	—	125	
	171	119	—	—	—	119	—	—	119	—	—	132	—	135	—	119	
	DARKNESS																
5/X	171	119	—	117	—	—	—	117	—	—	—	125	—	—	119		
	171	119	—	117	—	—	—	117	—	—	—	125	—	—	119		
	DARKNESS																
9/X	171	—	—	117	—	—	117	—	—	—	—	117	—	—	117		
	171	—	—	117	—	—	117	—	—	—	—	117	—	—	117		
	DARKNESS																
19/X	163	125	—	125	—	—	—	125	—	—	—	125	125	—	—		
	163	125	—	125	—	—	—	125	—	—	—	125	125	—	—		
	DARKNESS																
	Observer S., 44 years of age																
13/IX	278	149	—	156	—	—	—	140	—	—	—	278	—	—	149		
	289	149	—	151	—	—	—	142	—	—	—	181	—	—	156		
	DARKNESS							LIGHT STIMULATION						DARKNESS			
14/IX	289	153	—	139	—	—	—	139	—	—	—	400	250	153	—	149	
	278	149	—	139	—	—	—	139	—	—	—	208	198	175	—	160	
	DARKNESS							LIGHT STIMULATION						DARKNESS			
15/IX	327	151	—	139	—	—	—	137	—	—	—	278	—	181	—	181	
	313	149	—	139	—	—	—	137	—	—	—	175	—	163	—	175	
	DARKNESS							LIGHT STIMULATION						DARKNESS			
17/IX	341	214	—	175	—	171	—	171	—	—	—	250	—	—	259	—	
	341	241	—	175	—	167	—	171	—	—	—	250	—	—	242	—	
	DARKNESS							LIGHT STIMULATION						DARKNESS			
19/IX	379	153	156	—	151	—	—	153	—	—	—	327	—	259	—	—	
	318	153	153	—	151	—	—	156	—	—	—	313	—	268	—	—	
	DARKNESS							LIGHT STIMULATION						DARKNESS			
21/IX	327	198	175	—	181	—	—	175	—	—	—	341	327	—	—	313	
	343	198	175	—	181	—	—	178	—	—	—	327	313	—	—	327	
	DARKNESS							LIGHT STIMULATION						DARKNESS			
23/IX	327	179	171	—	171	—	—	—	175	—	—	—	327	—	198	—	
	327	179	171	—	171	—	—	—	175	—	—	—	268	—	234	—	
	DARKNESS							LIGHT STIMULATION						DARKNESS			

TABLE 1 (*continued*)

Date	Time Elapsed from the Beginning of the Dark Adaptation															
	1′	10′	20′	25′	30′	35′	40′	45′	50′	53′	55′	60′	65′	70′	75′	80′	85′
	Observer S., 44 years of age																
26/IX	358 358 DARKNESS	181 175	— —	181 179	— —	— —	— —	— —	198 198 LIGHT STIMULATION	— —	— —	— —	379 379	— —	379 379 DARKNESS	—	
29/IX	379 379	— —	198 198	— —	198 198	— —	— —	198 198	— —	208 208	— —	— —	234 242	— —	214 214	— —	203 203
	DARKNESS																
2/X	399 420	189 198	— —	— —	— —	198 198	— —	198 198	— —	— —	228 —	228 228	— —	189 —	189 198	— —	— —
	DARKNESS																
3/X	358 358	198 175	— —	— —	198 181	— —	— —	181 181	— —	— —	— —	228 234	— —	221 203	— —	198 198	—
	DARKNESS																
5/X	358 358	181 181	— —	179 179	— —	— —	— —	179 179	— —	— —	— —	198 198	— —	175 175	— —	— —	— —
	DARKNESS																
9/X	399 420	— —	— —	208 208	— —	198 198	— —	— —	— —	— —	— —	203 203	— —	198 198	— —	— —	— —
	DARKNESS																
19/X	399 399	198 198	— —	198 198	— —	— —	— —	198 198	— —	— —	— —	198 198	— —	198 198	— —	— —	— —
	DARKNESS																

* In the first line everywhere the electrical sensitivity of the right eye is indicated; in the second line—the same for the left eye; in the third line—the conditions of illumination. The light stimulation was always applied to the right eye; brightness of the light stimulation was 250 l. upon white. The electrical sensitivity is calculated always as the inverse value of the threshold, according to the formula $E = 1/S$, where S is the threshold expressed in microamperes (1.10^{-6} amp.); the electrical sensitivity corresponding to a threshold = 10.10^{-6} amp. is assumed to be equal to 1000.

could be observed and the sensitivity curves recovered their usual form.

The results of this series of experiments are shown (in mean values) upon table 1.

After a complete extinction of this conditioned reaction (in the sense given to this term by Pavlov) was achieved, we began a new series of experiments trying this time to obtain a similar reaction at the 40th minute of dark adaptation and not at the 50th minute as before.

This time a heightening of sensitivity having the character of a conditioned reflex was obtained much quicker than in the first series. Observer S. manifested it after 4 days of experiments with a light stimulation, observer P. after 5 days.

Now, that the fact of a heightening of electrical sensitivity of a conditioned reflex type was established, a number of questions arose. First of all the question, what exactly played the part of a conditioning stimulation? May be, it was not the time elapsed from the beginning of the dark adaptation but some other happening which took place during this time, some manipulation for instance, preceding the light stimulation, or it might be the time of day (the experiments taking place as a rule at the same hours—between 10.45 and 1 A.M.). This latter possibility, however, could be immediately excluded because one of the experiments of the first series (2/X) and one of the second (16/XI) had been shifted to the second part of the day (after 2 P.M.) and the 'conditioned' heightening of sensitivity occurred nevertheless in these experiments, just as in others of the same series.

The other supposition was put to test in the following manner:

The day after a considerable spontaneous heightening of electrical sensitivity on the 40th minute of dark adaptation had been attained (19/XI), the moment of the light stimulation was shifted to the 85th minute of the dark adaptation. Ten minutes before this moment the observers were warned that presently the light stimulation would be given. They were told to get ready for the light stimulation, to cover the left eye, to take their place before the screen. Five minutes after these directions were carried out, measurements of electrical sensitivity were taken for both eyes in the same manner as on other days, but no heightening of electrical sensitivity could be demonstrated. The observers were told again to be ready for the light stimulation, but it was actually given only 6 minutes later, and again measurements were taken in the interval. The result was the same—the electrical sensitivity remained at the same level as before the warnings were given. Both observers showed identical reactions (Table 2).

The results of this experiment permit us to eliminate the supposition that the heightening of electrical sensitivity observed by us could be conditioned by the experimental manipulations preceeding the light stimulation.

A similar experiment carried out a month later (14/XII), that is after a period during which the temporal conditioned reaction became entirely obliterated gave analogous results (Table 2).

TABLE 2

WHICH SHOWS THAT STAGING THE CONDITIONS PRELIMINARY TO THE LIGHT STIMULATION, 'GETTING READY' FOR IT, IS NOT SUFFICIENT TO CALL OUT A CONDITIONED HEIGHTENING OF ELECTRICAL SENSITIVITY IN A DARK ADAPTED EYE

Date	Observer	Time Elapsed from the Beginning of the Dark Adaptation in Minutes								
		10′	20′	30′	40′	45′	65′	70′	75′	80′
							Getting ready for the light stimul. 66–69′		Getting ready for the light stimul. 75–80′	
19/XI	P. I....	—	—	—	—	—	119	119	119	119
	II....	—	—	—	—	—	119	119	119	119
	S. I....	—	—	—	—	—	184	179	184	186
	II....	—	—	—	—	—	179	184	184	184
			25–30′ getting ready for the light stimul.		40–45′ getting ready for the light stimul.					
14/XII	P. I....	119	119	119	—	119	—	—	—	—
	II....	119	119	119	—	119	—	—	—	—
	S. I....	190	190	190	—	185	—	—	—	—
	II....	185	185	185	—	185	—	—	—	—
	M. I....	171	171	171	—	171	—	—	—	—
	II....	171	171	171	—	171	—	—	—	—

I, right eye
II, left eye
} electrical sensitivity.

After the elimination of the first and the second supposition there remains only the third—namely, that the heightening of electrical sensitivity is conditioned by the lapse of time from the beginning of the dark adaptation until the moment when the light stimulation was usually given.

Discussion

A question arises: can this 'conditioned' heightening of electrical sensitivity be considered as a conditioned reflex in the proper sense of the word?—We think that this question can be answered in the affirmative.

The general definition of a reflex, given by Descartes, of an involuntary reaction to an outside stimulation, embraces also the phenomenon observed by us.

If we take the definition of Pavlov who, together with other physiologists, sees the fundamental difference of a conditioned reflex from an unconditioned one mainly in the fact that the former is not an inborn but an individually acquired activity, then again the phenomenon observed by us seems to fall under this heading.

We cannot yet tell if we have to deal in this case with the usual chain of three links—receptor, center, effector—though theoretically we see no objection to it; there is no doubt that two links at least of the reflex arc are here present—the first and the second: 1, the receptor nervous apparatus, upon which acts a certain agent of the outside world (light in this particular case), 2, the nervous center, or centers, which transform and transmit the received impulse. Furthermore, the heightening of electrical sensitivity, observed by us (unconditioned in the case when the action of light took place, or 'conditioned' when it did not), indicates clearly that physiological changes are taking place in the substratum of this sensitivity either in the peripherical or in the central parts of the organ of vision.

Consequently, the central or peripherical parts (or maybe both) of the electrical sensitivity substratum can be considered to play the part of the effector.

Of course, all the questions which arise in connection with the conditioned heightening of electrical sensitivity observed by us will not be explained by the mere bringing of those facts under the category of conditioned reflexes; but a path for further investigation is thus indicated and other analogies come to mind, which may also be useful for the understanding and explanation of the experimental facts.

In particular, a paper by Feoktistova (**12**) permits us to trace an analogy between the facts above described and the secretory conditioned reflexes of a dog. Feoktistova experimented upon two dogs of which one was fed at regular intervals, the other given small portions of acid. After the procedure had been repeated about 140–150 times a spontaneous secretory reaction began to occur at a given moment, in one case a reaction to food; in the second—to acid, though now neither food, nor acid were given. By a series of experiments Feoktistova proved that here it is possible to speak of time as a specific stimulus for the saliva glands. Feoktistova thinks that these reflexes belong to the group of trace reflexes. Pavlov advances the same opinion in his lectures (**11**).

By bringing the facts observed by us under the heading of trace reflexes we shall by no means clear away all the difficulties. Indeed, the trace reflexes, that is, the postponed reflexes (as the term is commonly understood) could be postponed only for 3–5 minutes, and even that with considerable difficulty, while in our case we have to deal with much longer intervals.

Nevertheless, there is no doubt, that the nervous system of man or animals is able to keep fairly accurate time reckonings (*cf.* the experiments of Grabensberg and those of K. Frobenius (**13**)).

2. *The metronome sound as a conditioned stimulus for the reaction to light stimulation.*

The conditioned reflex nature of the phenomena observed by us and described above seemed definitely established; still we undertook further steps for the verifying of this supposition. Therefore we devised a series of experiments along typical lines for creating conditioned reflexes in animals. Three observers—P., S., and M. were selected, all three well trained. Our aim was to create in them a 'conditioned' light reaction to the sound of the metronome (120 beats per minute). The conditions were the same as in previous experiments, that is, the observers remained in a dark room long enough for the electrical sensitivity to reach a steady minimum. The sound of the metronome being by itself a kind of auditive stimulus which could perhaps act as an unconditioned stimulus upon

the electrical sensitivity, we tried first the action of the metronome sound separately, without connecting it in any way with the light stimulation. The observers were somewhat surprised by this innovation but declared immediately that "the sound did not disturb them—no more than the ticking of a clock," and indeed no change of electrical sensitivity could be detected subsequent to the action of the metronome alone.

On the next days the experiment went as follows: the observers remained in a dark room until the electrical sensitivity reached a steady level; then, but everytime at a different moment of the dark adaptation, the metronome was started (120 beats per minute). Two minutes after the sound had begun the screen before the eyes of the observers was illuminated (its brightness being about 250 luxes on white). The sound of the metronome went on for 3 minutes after the beginning of the light stimulation; the duration of the latter being 10 min. The electrical sensitivity was measured twice —before the starting of the metronome and immediately after the end of the light stimulation. It rose considerably after the light stimulation, as in previous experiments.

This combined action of light and metronome was repeated 4 times for observer S., 3 times for observers P. and M. Observer S. had it on the 46th, the 37th, the 90th and the 22nd minutes of the dark adaptation; observer P.—on the 46th, 37th and 90th minutes; observer M.—on the 46th, the 37th and the 23rd minutes.

Now, without giving any warning to the observers as to the alteration of the usual course of the experiment, we subjected them to the action of the metronome sound alone, unaccompanied this time by light stimulation. The duration of the sound was 5 min. as usual. Observers P. and S. had it on the 23rd minute of the dark adaptation, observer M. on the 17th minute. Observers P. and M. immediately manifested a conditioned reaction: a heightening of the electrical sensitivity subsequent to the sound could be stated on the very first day. Observer S. gave indefinite results, although she previously underwent 4 combinations of light and sound

and had been warned moreover that the sound of the metronome would always be accompanied by the illumination of the screen. After minute inquiries we succeeded in elucidating an important point, namely that on the night before S. had been inhaling ether in such a quantity as to have a headache afterwards and insomnia. On the same day all three observers were again subjected to the action of the metronome sound accompanied by light stimulation; on the next day the sound of the metronome was given separately and all three, including S., manifested a conditioned heightening of the electrical sensitivity (see Table 3).

It follows from the experiment that the sound of the metronome can act as a conditioned stimulus for electrical

TABLE 3

CONDITIONED ACTION OF THE METRONOME SOUND WHEN GIVEN ALONE (120 BEATS PER MIN.) UPON THE ELECTRICAL SENSITIVITY OF A DARK ADAPTED EYE

Date	Observer	Time Elapsed from the Beginning of the Dark Adaptation in Minutes										
		10′	15′	20′	25′	28′	30′	40′	53′	60′	70′	85′
				Metronome 22–27′								
29/XI	P. I...	119	—	117	—	129	140	127	—	119	—	—
	II...	119	—	117	—	129	140	122	—	119	—	—
	S. I*..	175	—	171	—	189	189	163	—	167	—	—
	II. .	175	—	167	—	171	163	163	—	167	—	—
									Metronome 54–59′			
1/XII	P.I...	119	—	—	—	—	—	—	117	137	137	117
	II...	119	—	—	—	—	—	—	117	137	137	117
	S. I...	185	—	—	—	—	185	—	185	228	250	185
	II...	185	—	—	—	—	185	—	185	228	250	185
			Metronome 18–23′									
2/XII	S. I...	179	179	—	221	—	214	189	185	—	—	—
		179	179	—	234	—	228	189	185	—	—	—
	M. I..	167	167	—	228	—	185	171	175	—	—	—
	II..	167	167	—	214	—	185	171	175	—	—	—

* Observer S. had been inhaling ether on the night before the experiment.

I, right eye
II, left eye
} electrical sensitivity.

sensitivity just as time did in our previous experiments. This demonstrates the assumption that any indifferent agent may be turned into a conditioned stimulus for this kind of sensitivity.

It seems a significant fact that the formation of a conditioned sensory reflex to light requires much less time than for the formation of a defensive motor reflex in normal adults or that of a secretory reflex in dogs. Our observers needed no more than 5–6 combinations of a light stimulation with an indifferent agent to form a conditioned sensory reflex, while with Feoctistova dogs about 140–150 experiments were necessary and even then the secretory reflex was only beginning to form itself. As to the conditioned defensive motor reflex it seems that sometimes it does not manifest itself at all at least in humans (Miassischev (**9**), Beritov and Dzidzishvili (**3**)).

The work of Beritov and Dzidzishvili shows that in the cases where such a conditioned reaction does not manifest itself a conditioned reflex is nevertheless formed, it exists potentially and is only consciously inhibited. We also consider it impossible to eliminate entirely the subjective attitude of the observers towards the experiment, conscious, or unconscious, we are aware that this factor must modify to some extent the results of the experiment.

The common belief is of course that the sensory sphere cannot be directly controlled by consciousness (and here lies the difference from the motor sphere). Nobody can improve one's visual acuity at will. But the fact that the subjective attitude of the observer towards the experiment can modify subjective results seems established beyond doubt. The work of Altenburger and Kroll (**1**) shows, for instance, how suggestion can influence the chronaxy of cutaneous sensibility and the adequate optical chronaxy. It may then be supposed that the subjective attitude of the observers would not be without influence upon their electrical sensitivity. In order to verify this supposition we undertook a third series of experiments.

Influence of conscious will or subjective attitude of the observers upon the level of electrical sensitivity of the eye.

First of all, we tried to investigate the question as to how far the subjective attitude of the observer may influence the already formed conditioned heightening of electrical sensitivity. The experiment proceeded as follows: having ascertained that the conditioned reaction was already formed (observers P. and S. manifested a quite clear conditioned heightening of electrical sensitivity at a given minute of dark adaptation—see data relating to 19/XI), on the next day when the experiment was just started we told the observers as if accidentally: "today you shall have no light stimulation." The same was repeated two or three more times during the dark adaptation period. This reiteration of the instruction the observers attributed to the experimentator's absent-mindness, they told later to a third person—"He most probably forgot that we were told already, we remembered well enough, no need repeating."

On this day no heightening of electrical sensitivity could be stated at the minute when it usually occurred (40–50 minutes after the beginning of the dark adaptation). (See Table 4.)

This phenomenon cannot be attributed to the 'extinction' of the conditioned reflex because on the next day when the observers were warned that the 'light stimulation' would take place a considerable heightening of the electrical sensitivity was observed on the 40–50 min. of the dark adaptation (although the light stimulation was given only on the 60th minute).

The conditioned reaction to the metronome was tested in a similar manner (see table 6).

After making sure that all three observers manifested a clear conditioned reaction to the sound of the metronome we told them that hence forward the sound of the metronome would not be accompanied by illumination of the screen so they need not pay any attention to it and should not get ready for the light stimulation. On the first day when this new instruction was given observers S. and M. still manifested a heightening of electrical sensitivity synchronous with the ticking of the metronome though a much feebler one than on

TABLE 4

AN ATTEMPT TO INHIBIT AN ALREADY ACQUIRED CONDITIONED HEIGHTENING OF ELECTRICAL SENSITIVITY OCCURRING ON THE 40–50TH MINUTE OF THE DARK ADAPTATION. SUMMARY OF RESULTS

Date		Time Elapsed from the Beginning of the Dark Adaptation in Min.										
		1′	10′	30′	35′	40′	43′	50′	55′	60′	70′	80′
Observer P.												
19/XI	No warning given	163	117	117	—	—	127	137	—	129	119	113
		171	117	117	—	—	127	137	—	129	119	113
						DARKNESS						
20/XI	Observers warned that today no l. stimul. would be given	171	119	117	—	—	119	119	—	119	119	—
		171	119	119	—	—	119	117	—	119	119	—
						DARKNESS				L. stimul. 60–69′		
21/XI	Obs. warned that today they would have a l. stimul. as usual	175	119	117	—	—	129	—	140	—	171	129
		171	119	117	—	—	132	—	140	—	156	140
						DARKNESS						
25/XI	Warning: No light stimul. today	175	119	—	119	—	—	125	—	117	—	119
		175	119	—	119	—	—	125	—	122	—	117
						DARKNESS						
Observer S.												
19/XI	No warning at all	398	185	189	—	—	203	234	—	250	203	175
		398	185	179	—	—	203	234	—	250	208	185
						DARKNESS						
20/XI	Warning: No light stimul. today	410	179	179	—	—	185	185	—	185	179	—
		410	179	179	—	—	185	185	—	179	185	—
						DARKNESS				L. stimul. 60–69′		
21/XI	Warning: Today a l. stimul. as usual	399	189	189	—	—	214	—	234	—	506	214
		189	189	189	—	—	214	—	234	—	278	214
						DARKNESS						
25/XI	Warning: No light stimul. today	379	185	—	179	—	—	179	—	171	—	175
		379	185	—	185	—	—	185	—	175	—	179
						DARKNESS						

TABLE 5

CONSCIOUS INHIBITION OF AN ALREADY ACQUIRED CONDITIONED HEIGHTENING OF THE ELECTRICAL SENSITIVITY (CONDITIONED BY THE SOUND OF THE METRONOME) IN A DARK ADAPTED EYE

Date	Obs.	Time Elapsed from the Beginning of the Dark Adaptation in Minutes						Note
		43	53	63	70	76	81	
			Metronome 58–63′					
2/XII	S. I.....	189	185	203	189	—	—	Before starting the metronome the observers were warned that the sound of the metronome would not be accompanied by light stimulation.
	II.....	189	185	189	189	—	—	
	M. I.....	171	175	189	185	—	—	
	II.....	171	175	171	185	—	—	
					Metronome 70–75′			
3/XII	P. I.....	119	119	—	119	119	119	
	II.....	119	119	—	119	119	119	
	S. I.....	190	199	—	190	196	196	
	II.....	186	185	—	185	190	190	
	M. I.....	185	185	—	175	185	190	
	II.....	171	185	—	185	171	175	

I, right eye
II, left eye } level of electrical sensitivity.

previous days (experiment on 2/XII). On the following day a total absence of any changes of sensitivity subsequent to the action of the metronome could be stated. Observer P. gave clear results even on the first day—the conditioned reaction to sound was stopped entirely (experiment on 3/XII). Thus our supposition seemed demonstrated: the subjective attitude of the observers is apt to modify 'conditioned' reactions of the electrical sensitivity of the eye.

Then we went further in our reasonings. If the subjective attitude can stop the conditioned heightening of electrical sensitivity, then maybe we could demonstrate the opposite: by suggesting a mental attitude corresponding to the conditions which usually bring out a heightening of sensitivity we could obtain such a heightening though no real conditions to elicit would be present. We instructed the observers, placed

as usual in a dark room, to imagine during 10 min. the conditions of the light stimulation as vividly as they could, and especially to try to see the illuminated screen before them just as it appeared when presented to them in reality. On the first day observers P. and S. (1/XII) found it hard to imagine a lighted screen for 10 min. "We cannot concentrate" they confessed. S. manifested no change of sensitivity, P. showed a slight heightening after the 10 min. assigned for picturing the lighted screen to themselves.

TABLE 6

THE IMAGINING OF A LIGHTED SCREEN CAN CALL OUT A HEIGHTENING OF THE ELECTRICAL SENSITIVITY OF THE EYE

Date	Obs.	Time Elapsed from the Beginning of the Experiment					
		70–72	80–82	85–95	96–98	110–112	120–122
3.11.35	M. 1	185	190		228	218	190
	2	170	176		176	218	180
	C. 1	195	195		215	203	190
	2	190	190		228	208	186
	P. 1	120	120		135	133	123
	2	120	120		136	132	123

1, right eye
2, left eye } level of electrical sensitivity.

On another day all three observers (P. S. and M.) were more successful in imagining a lighted screen: all of them manifested also a marked heightening of electrical sensitivity; then, after a certain lapse of time, the sensitivity dropped to its former level (table 6).

This heightening could not be accidental. The fact that not only one point but quite a number of them lay here on a higher level than the usual dark adaptation curve demonstrates this positively. This heightening was not momentary but distributed over a considerable period of time.

It cannot be a result of fatigue following mental stress. The experiments of Makarov (**8**) and Shemiakeen (**14**) show

that intense brain work produces a sinking, not a heightening of electrical sensitivity of the eye.

These last experiments do not contradict the former ones. Of course, in the former series although a subjective attitude was suggested to the observers (instruction to 'get ready' for the light stimulation) still no heightening of sensitivity occurred; but this proves only that such an attitude is insufficient to start the mechanisms controlling the heightening of electrical sensitivity. And it seems quite probable that by careful training a conditioned heightening of electrical sensitivity could be obtained in response even to this complex of stimuli.

There can be hardly any doubt that the rule observed by us for the electrical sensitivity of the eye must be valid for all the sensorial sphere.

The possibility of creating 'conditioned' sensory reactions (reflexes) in men, also the part played in the process by the subjective attitude, opens, it seems to us, new ways for the application of the method of electrical sensitivity measurements for solving many psychological and psychophysiological problems (particularly, for the analysis of inborn, individually acquired or conscious sensitivity factors).

There is ground to think that this method may be used even for solving certain problems of human psychology. Many data obtained in psychophysiological experiments will find most probably an explanation, some fully, some in part, if one takes into consideration the phenomena above described.

Summary

1. If a person had been subjected to a series of experiments in which a light stimulation was given him at a certain minute of the dark adaptation occasioning a subsequent heightening of electrical sensitivity both in the stimulated and in the non-stimulated eye, then this person becomes apt to manifest a similar (though less pronounced) spontaneous heightening of electrical sensitivity at the same minute of the dark adaptation with light stimulation.

2. This phenomenon can be understood as a sensory reflex conditioned by the time elapsed from the beginning of the dark adaptation.

3. A special series of experiments confirmed the supposition that a positive conditioned sensory reflex could be created by other up to this time indifferent agents (the sound of the metronome).

After the sound of the metronome had been combined several times with the light stimulation, a heightening of electrical sensitivity could be called out by the sound of the metronome alone unaccompanied by light stimulation.

4. The subjective attitude of the observer can influence a conditioned sensory reaction already acquired. We have observed an inhibition of an acquired sensory reflex depending upon certain attitudes suggested to the observer.

5. On the other hand, a vivid mental image of an illuminated screen can call out a heightening of electrical sensitivity in the unstimulated eye.

6. The phenomena observed by us are typical most probably for the whole sensorial sphere.

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ON THE DISCRIMINATION OF MINIMAL DIFFERENCES IN WEIGHT. III. THE RÔLE OF FREQUENCY

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I

In several sensory modalities, differential sensitivity is known to decrease as the stimulating intensity is made to increase. Differential sensitivity to white light ($1/\Delta I$), for example, varies inversely with brightness (I, in photons) in a manner that is approximately hyperbolic in form (**2**, **9**, **12**, **19**, **23**). For a constant exposure-time and level of brightness, however, $1/\Delta I$ in general tends to increase with an increase in the size of the retinal image (**13**, **25**). For fixed values of brightness and retinal area, moreover, $1/\Delta I$ varies directly with exposure-time (**14**). These findings were interpreted in terms of a neurophysiological theory of differential sensitivity. Visual differential sensitivity was found to vary directly with the number of elements (= number of impulses per unit of time) available for the discrimination of a just noticeable difference in intensity of stimulation. This interpretation makes differential sensitivity the *supplement* of the volley theory of sensory intensity (**32**).[1]

Experiments analogous to those mentioned for vision have also been carried out in audition for loudness at a frequency of 800 *c. p. s.*, with the result that new information has been secured concerning the mechanism of hearing (**3**, **28**, **29**). The reported data can be accounted for in terms of the theory stated above.

For kinesthesis, it was found that differential sensitivity decreases with stimulating intensity (**11**, **15**, **16**), but increases as the number of elements presumably involved in

[1] The ideas basic to this notion at once call to mind a possible parallel in Lashley's principle of mass action (**22**).

the discrimination was made to increase (**15, 30, 31**). In another study it was possible experimentally to demonstrate that differential sensitivity to weight increases as the total number of elements available for the discrimination was made to increase. Under comparable conditions, bimanual is greater than is unimanual differential sensitivity (**16**).

The influence of frequency upon differential sensitivity has not been investigated systematically. The suggestion has been ventured that $1/\Delta W$ (expressed as a function of the *rate* of lifting) would gradually approach and then pass through a maximum. The purpose of the experiment reported in this paper is (*a*) to establish the form of the function relating differential sensitivity ($1/\Delta W$) and the frequency of lifting (F), and (*b*) to discuss the relation that exists between differential sensitivity and discriminatory precision.

Method, Apparatus and General Procedure.—As a psychophysical concept, differential sensitivity has most frequently been employed with reference to the discrimination of minimal differences in the intensity of stimulation. As originally used by Weber (**30, 31**), Aubert (**2**), Helmholtz (**10**), G. E. Müller (**24**), and others, its definition was established as the reciprocal of the 'absolute' difference between the two stimulating intensities required to occasion the report of a just noticeable difference. Such differences have been estimated by various procedures. From the standpoint of psychophysiological interpretation, however, a method of limits appears to have been the most fruitful. Under rigorously defined experimental conditions the procedure involves a controlled increase or decrease in stimulating intensity until the critical response is eventuated. Such results can be secured rapidly, accurately, and are optimally useful from a psychophysiological point of view.[2]

In the present experiment a method of limits was used (simultaneous presentation; direction of increase; continuous change). To determine the relationship between $1/\Delta W$ and F, eight frequencies were chosen: 30, 60, 90, 120, 150, 180, 210 and 240

[2] Reviewers of psychophysical methodology have at times advocated the incorporation of results secured by the process of equating stimuli. To introduce equality-data in this way, however, may obscure the physiological meaning of the final result, and individuals actually productive in the experimental field have seldom employed this possibly confusing practice. The recognition of a difference is by no means the same thing as the suppression of a difference; the operations involved in the two cases are physiologically quite distinct. If we are ever to achieve anything more than a merely superficial appreciation of the neurological implications of psychophysical results, the advantages provided by such distinctions must not only be recognized but must also be continued in actual practice. By the same token, there exists no secure reason why the laws for the recognition of minimal *in*crements should be the same as those for minimal *de*crements. As a matter of fact, it is becoming experimentally more and more apparent that even here a quantitative difference is to be expected (*cf.*, *e.g.*, **3, 8, 26**). Then, too, there is the interesting question of the *rate* of application of the stimulus (**7**).

per minute. These frequencies were selected on the basis of results obtained during the practice-period which preceded the experiment proper. Care was taken to employ frequencies which were not so high as to be accompanied by strain, fatigue, or other disturbing effects.

At each of the eight points, $1/\Delta W$ was measured by psychophysical procedure for three observers (the writers). Two weights were employed: each $W = 100$ grm. These weights (two fiber cylinders) were lifted to a height of 2.5 cm., using the wrists as fulcrums, and then lowered; the rhythms were established by practice and governed by a metronome. The frequencies were employed in haphazard order. The stimulus-attitude was adopted by the observers.

One of the weights was continuously increased at a constant rate until the observer signalled that the adjusted weight was just noticeably increased (**15**). The average difference between the adjusted and the standard weight determined the magnitude of ΔW. Throughout the experiment, the average of 10 observations constituted our measure of a just noticeable difference, ΔW. Values for the left and for the right hands were obtained from an observer at each of the eight frequencies on a single day. On the following day, the entire experiment was repeated.

Differential Sensitivity and Frequency.—Table I contains the values necessary for a psychophysical description of the mechanism studied under these conditions. Each entry for an individual observer is an average of 10 measurements. $\sigma_{\Delta W}$ is the root-mean-square deviation of the distribution upon which a mean ΔW is based. Relations existing among the values entered in the table may be perceived with greatest economy, visually: see Fig. 1.

The curves exhibited in this figure show the manner in which differential sensitivity ($1/\Delta W$) varies as a function of frequency (F) for each of the three individual observers. The abscissae are spaced logarithmically for convenience. The circles shaded on the left stand for values secured when the weight held in the left hand was made to increase; those shaded on the right, for values obtained when the adjusted weight was supported by the right hand. Each circle is an average of 20 measurements. All functions are similar in form: $1/\Delta W$ at first slowly increases, approaches and passes through a maximum, decreases and finally slopes off, as if tending to approach a limiting value. This description is specific to all of the functions shown; it therefore describes the most probable function relating differential sensitivity to the frequencies employed (**17**, **33**).

Theory.—These experimental results have definite implications for the *activities* of the individual nerve fibers con-

TABLE I

RESULTS FOR 2 SETS OF EXPERIMENTS

Each entry is based on 10 measurements for an individual observer. F is the frequency of lifting (in no. per minute); ΔW is the difference between the standard and the adjusted weight (in grams); $\sigma_{\Delta W}$ is the root-mean-square variation of the distribution upon which ΔW is based. In any cell, the upper set of values was obtained in the first experiment; the lower set, in the second experiment. See text.

F	A. H. H.		J. E. S.		M. J. Z.	
	Left Hand	Right Hand	Left Hand	Right Hand	Left Hand	Right Hand
	$\Delta W \pm \sigma_{\Delta W}$	$\Delta W \pm \sigma_{\Delta W}$	$\Delta W \pm \sigma_{\Delta W}$	$\Delta W \pm \sigma_{\Delta W}$	$\Delta W \pm \sigma_{\Delta W}$	$\Delta W \pm \sigma_{\Delta W}$
30	28.783 ± 3.49	46.806 ± 9.97	60.256 ± 8.71	37.391 ± 7 53	74.782 ± 15.43	50.11 ± 19.26
	64.103 ± 13.35	31.546 ± 4.53	58.373 ± 4.26	67.788 ± 8.76	50.303 ± 14.58	88.898 ± 9.34
60	24.21 ± 1.9	37.929 ± 3.43	63.215 ± 5.32	31.742 ± 3.27	59.449 ± 8.43	38.198 ± 5.27
	42.918 ± 6.02	26.316 ± 3.66	56.795 ± 5.52	71.823 ± 4.67	54.338 ± 4.1	79.62 ± 17.91
90	22.327 ± 1.48	24.748 ± 2.75	29.55 ± 2.44	45.999 ± 3.76	40.35 ± 6.53	22.865 ± 8.05
	27.174 ± 5.95	29.412 ± 2.10	47.344 ± 3.39	52.455 ± 6.26	32.818 ± 6.61	73.437 ± 11.85
120	26.631 ± 4.29	32.011 ± 8.94	42.711 ± 6.93	44.116 ± 2.81	37.929 ± 2.59	33.894 ± 7.79
	25.189 ± 5.31	28.571 ± 7.07	42.502 ± 1.43	47.075 ± 1.77	21.53 ± 1.47	30.128 ± 2.31
150	31.473 ± 2.8	29.859 ± 3.43	45.461 ± 9.71	37.122 ± 7.81	31.204 ± 1.67	36.046 ± 3.50
	27.027 ± 2.96	36.101 ± 4.15	43.309 ± 1.76	47.882 ± 3.59	27.169 ± 0.98	36.853 ± 6.36
180	41.96 ± 4.07	32.28 ± 3.83	56.755 ± 8.85	47.344 ± 4.60	36.853 ± 7.60	41.426 ± 8.67
	28.571 ± 4.88	41.322 ± 8.12	53.262 ± 5.16	53.531 ± 2.17	22.327 ± 4.16	42.502 ± 10.98
210	61.87 ± 8.29	37.391 ± 4.79	65.905 ± 8.46	61.063 ± 6.02	34.432 ± 2.92	39.66 ± 4.58
	32.154 ± 6.79	52.632 ± 5.67	67.788 ± 4.02	56.49 ± 3.50	32.28 ± 2.55	33.625 ± 15.51
240	66.712 ± 6.86	41.964 ± 5.37	80.000 ± 11.32	74.074 ± 13.09	34.364 ± 11.43	39.216 ± 13.28
	33.557 ± 8.01	58.824 ± 10.71	74.782 ± 4.74	60.794 ± 2.50	41.695 ± 1.98	40.081 ± 7.04

cerned. As the frequency of lifting is initially made to increase, the number of fibers, and thus the number of elements available for the discrimination of a minimal increment in weight may be assumed also to increase. Up to the point of maximal sensitivity, the results obtained in the present experiment can thus be brought into line with a neurophysiological theory of differential sensitivity (*vide supra*).

Our subjects reported negatively as regards the appearance of strain and fatigue effects throughout the experiment. At frequencies above the point of maximal sensitivity, $1/\Delta W$ nonetheless decreases. This can be taken to mean that the number of elements available for the discrimination must also

decrease. It is to be expected that the number of excited nerve fibers will reach a maximal level as F is made sufficiently to increase under the conditions of this experiment. If we assume that the initial appearance of this maximal level coincides with the experimentally determined level (ideally, a

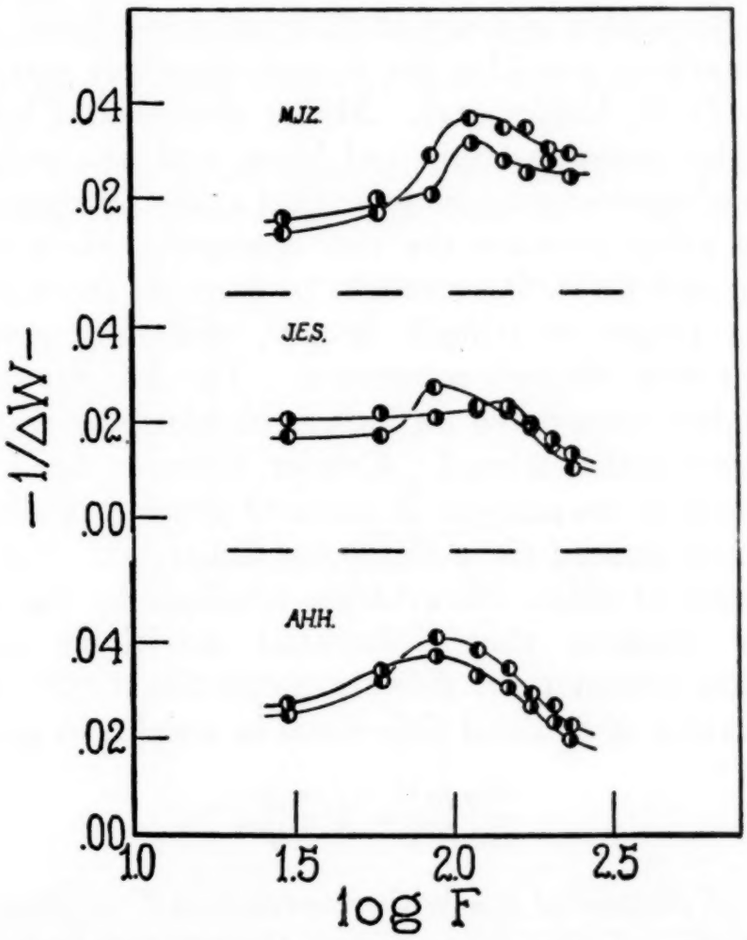

FIG. 1. *Kinesthetic differential sensitivity* to weight *vs. frequency* of the lifting rhythm for three observers (the writers). Each circle is an average of 20 measurements for an individual observer. The circles shaded on the left are for the left hand; those shaded on the right, for the right hand. ΔW is measured in grams; F, in the behavioral units of 'number of lifting movements per unit of time.' W, the standard weight (= 100 grams), is a parameter. Each curve passes through a maximum as is to be expected from neurophysiological considerations. See text.

point) of maximal sensitivity, then, as F is additionally made to increase, the number of elements (= number of nerve impulses per unit of time) available for the discrimination in question must accordingly decrease. In this way, the relationship between differential sensitivity and frequency for

any one subject as determined under the conditions of the present experiment can be accounted for in terms of established principles concerning the activities of individual nerve fibers (1).

Differential Sensitivity and Discriminatory Precision.—The first systematic attempt to consider the nature of the relationship between a measure of differential sensitivity and one of observational precision for human observers was perhaps made by G. E. Müller (24). Müller discussed at length the relation, its probable origin and locus, and he concluded on the basis of experimental evidence that a direct proportionality probably exists between the two concepts. More recently, Thomson and Culler have sought to examine the relation for restricted ranges of stimuli (6, 27), and their results are consistent with Müller's contention. The data for several of these studies were based on indices obtained by way of the method of constant stimuli. Crozier, however, has indicated an approach to the problem in terms of physiologically intelligible results secured *via* a method of limits (4). For several departments of sense, the evidence obtained by this method definitely suggests that differential sensitivity and discriminatory precision are directly proportional (5). For the discrimination of minimal differences in weight, in general,

$$\frac{d(\sigma_{\Delta W})}{d(\Delta W)} = k' \frac{\sigma_{\Delta W}}{\Delta W}. \qquad [A]$$

The rate of change of $\sigma_{\Delta W}$ with respect to ΔW is proportional to the ratio of the magnitudes themselves (12). When $\sigma_{\Delta W} = k''\Delta W$, then

$$\frac{d(\sigma_{\Delta W})}{d(\Delta W)} = k. \qquad [B]$$

Whether or not the relation symbolized in Equation [B] is always obeyed precisely for all sense-departments cannot profitably concern us here. Points to be emphasized are (*a*) that *each* of these variables is organically determined, and (*b*) that, whatever its precise nature, the law relating ($\sigma_{\Delta W}$) and (ΔW) is intrinsically a law of the test-organism (consider, *e.g.*, 17).

We have already indicated that this relation, in its more general form (*cf.* Equation A), may be independent of the mode of discriminating for a wide range of W-values (**15**). If it can now be shown that the same general tendency exists between $\sigma_{\Delta W}$ and ΔW as frequency is varied, but as the value of W(= 100 grm.) is held constant, we have then acquired further evidence to support our belief that the general relation is an *organic invariant* (**18**)—an invariant law of the human organism.

Figure 2 depicts the experimental verdict as regards the results obtained from our three observers. In each case,

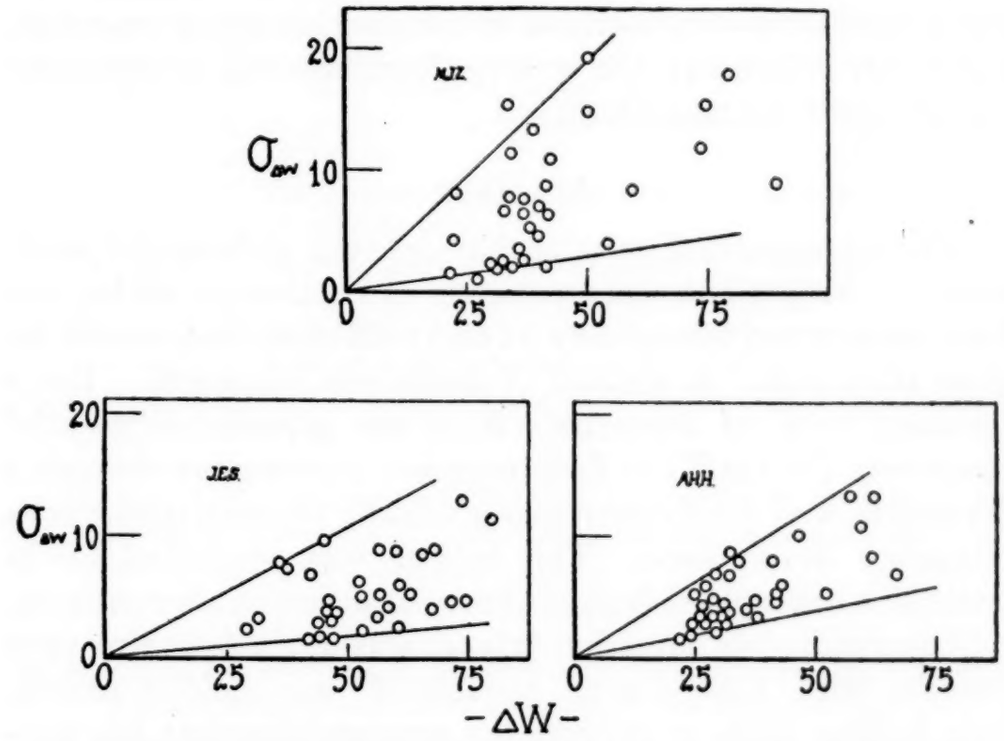

FIG. 2. *Precision of judgment* and *differential sensitivity* to weight. Graphs showing the relationship between $\sigma_{\Delta W}$ (= root-mean-square variation) and ΔW for 3 observers. Each circlet is based on 10 measurements: *cf.* Table I. Every ordinate-value has a standard deviation ($\sigma\sigma_{\Delta W}$) which is directly proportional to the magnitude of the ordinate itself. In these experiments, the standard weight was a parameter; frequency, the variant. The enclosing limits are drawn on the hypothesis that $\sigma_{\Delta W} = k\Delta W$.

$\sigma_{\Delta W}$ can be seen to increase with ΔW. Each plotted point is founded on 10 measurements for an individual subject; each ordinate, therefore, has itself a standard deviation (= $\sigma_{\sigma\Delta W}$)

that is directly proportional to its own magnitude. The enclosing limits are drawn in accordance with the theoretical expectation that a direct proportionality exists between these two organically determined variables. A complete determination of the quantitative nature of this relationship must of course wait upon the results of a more extensive investigation. For the data in hand, however, the agreement between theoretical expectation and experimental finding is clear. Differential sensitivity ($1/\Delta W$) and precision of judgment ($1/\sigma_{\Delta W}$) are lawfully related, and by a function that closely approximates one of direct proportionality. These facts support the conception which entertains the idea that $\sigma_{\Delta W}$ is a measure of a capacity intrinsic to the discriminating organism, and is *not* principally the result of instrumental or methodological 'errors in measurement.'

Summary

The experimental relationship between differential sensitivity to weight and the frequency of rhythmical lifting has been determined bimanually at eight different frequencies for three observers. A method of limits was employed. For a constant level of intensity (W = 100 grams), differential sensitivity ($= 1/\Delta W$) at first increases, then passes through a maximum, and finally decreases gradually for each observer as frequency is increased. This finding was accounted for in terms of a neurophysiological theory of differential sensitivity.

Discriminatory precision ($1/\sigma_{\Delta W}$) was again found to vary directly with $1/\Delta W$—even though W was held constant. This finding tends to support the presumption that the relation between these two concepts may be an *invariant* property of the human subject.

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THE AGE DIFFERENCE IN THE HEDONISTIC TENDENCY IN MEMORY

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History and Significance of the Problem

Educational psychology and psychoanalysis come together from different corners of the earth, as it were, and agree on at least one principle: the hedonistic tendency in memory. Expressed in terms of repression or censorship of associations unpleasant to the ego by Freud, and formulated as the law of effect by Thorndike, the principle remains essentially the same;—the more efficient retention of pleasant associations than unpleasant ones, or *hedonistic selectivity* in memory.

The only two points on which the experimenters up to 1929 seem to agree are: that Freudian theory is badly in need of experimental verification, and that all previous attempts to do so in respect to this particular problem have been invalid. Wohlgemuth (**18**), for example, says: "The statement that unpleasant experiences are more easily forgotten than pleasant experiences is often found in psychoanalytic literature. Whether this is true or not can, I believe, only be settled by experimental psychological investigation; psychoanalysis does not and cannot furnish a scientific proof one way or the other." He then goes on to criticize the validity of previous studies, only to suffer a like fate at the hands of subsequent investigators.

The last word in this series of successive criticisms during this period of unsatisfactory investigation of the problem was spoken by Meltzer in an admirable critical review which appeared in 1930 (**10**). Meltzer pointed out the procedural as well as logical fallacies in almost all of the twenty-six experiments published from 1898 to 1929, and was probably responsible in no small measure for the decided change for the

[1] The author is indebted to Dr. T. A. Jackson for the supervision of this experiment.

better which the experimentation on this problem underwent at that point.

In commenting on the serious disagreements in the results of the investigations before 1932, Beebe-Center (2) points out the possibility that some of them, at least, may be accountable on the basis of age differences. Wohlgemuth, for example, obtained negative results using children, while several other investigators obtained positive results using adults.

That such a possibility exists is furthermore unintentionally testified by most of the studies published since Meltzer's review. Rosenzweig and Mason (13), for example, find no group differences in the memory value of pleasant and unpleasant material (P and U), and agree with Wohlgemuth in denying the hedonistic advantage. They do report, however, that such individual differences as are found seem to be a function of the *M.A.* of the children used as subjects.

Carter (4) obtains positive results using children in the 6th and 7th grades at the beginning of his series of experiments, and presumably in the 8th and 9th grades at the conclusion. This would probably correspond roughly to the upper M.A. group in Rosenzweig and Mason's study, which also yielded positive results.

Coming now to the work of Thompson (17), the only one using adolescents (high school students) as subjects, we find a *slight* hedonistic selectivity in the *freshman* group, and a *more pronounced* selectivity in the group of *upper classmen.*

Of the 12 studies using college students as subjects, 8 show positive results for the superior memory of the P as against U, 2 show negative results, and 2 show both. All the negative results, however, can be accounted for either on the basis of 'unequal affective decrement' in the affective evaluation of past experiences, or by the fact that immediate and not delayed recall was used in the memory test. The first refers to the phenomenon noted by more than one experimenter, that both P and U experiences tend to lose their affective value as time goes on, but the U experiences suffer more in this respect. Obviously this fact should not be ignored in evaluating results. The second explanation im-

plies that immediate recall is not a fair test of hedonistic selectivity in memory. As an experimental test of the Freudian hypothesis, it would certainly seem that we should give whatever it is that he calls the censor in memory a little time to operate. From the point of view of the law of effect also, we can hardly draw conclusions from the special case of immediate recall.

This analysis of recent experiments confirms Beebe-Center's suspicion and leads to our hypothesis: *that there is a development of hedonistic selectivity in memory from childhood to adulthood.* It is for the purpose of a preliminary test of this hypothesis that the present experiment is conducted. If affirmed, it would not only throw light on some of the results of previous experiments and establish the necessity for controlling the age factor in future experiments of this sort, but might have theoretical significance in developmental psychology.

Procedure and Results

Twenty children and twenty adults were used as subjects in this experiment, as a preliminary test of our hypothesis. The children were pupils in the upper 4th year (4B) class in a N. Y. C. public school, averaging 9½ years in age with very little deviation. The adults were students, teachers-in-training (laymen), and office-workers in the Adult Education project, ranging in age from 30 to 65, averaging about 40. College students were not used as subjects, as in most previous experiments, because they were not considered sufficiently representative of an adult group, for the purpose of this experiment.

Affectively-toned words were used as the most easily controlled means of comparing P and U memory values objectively, although personal experiences, odors, puzzles, school marks, titles of poems, and current events have also been used. The complexity of associations involved in these, and the difficulty in obtaining valid affective-tone ratings, as well as the 'unequal affective decrement' that some undergo between immediate and delayed recall, offset the value of their closer resemblance to the real life situation.

The following procedure determined the selection of words to be used in the memory test: A list of fifty words was selected from lists used by previous investigators and a few added by the author. This list was distributed to 85 children and 85 adults comprising groups similar to those from which the subjects were later chosen. None of the actual subjects, however, received this preliminary list. In this way the possibility of insight into the hedonistic aspect of the memory test was ruled out. This is a factor which has not often been controlled. The subjects in this preliminary investigation were instructed to underline in the first of two identical columns of words all the words which they considered pleasant, and to put a cross next to each of the three words considered most pleasant of all. The same procedure was to be followed for unpleasant words in the duplicate column. Instructions were further elaborated

for the children, for whom 'pleasant' was defined as "something you like, or something you like to think about," and 'unpleasant' correspondingly. The adults were merely told to judge by their own subjective reactions to the words. It was the experimenter's original intention to use the same list for both children and adults in the memory experiment, since it was expected that a list of 50 words would yield at least 5 P and 5 U words on which both children and adults would agree. The tabulation of results, however, showed such distinct differences between the two groups, that there was no alternative but to make separate lists, although there was some overlapping.

In order to eliminate the recency-primacy advantage in the order of presentation of the list of words selected for the test, the list of ten test words was padded by adding two indifferent words at the beginning and two at the end of the list. The P and U words were placed alternately, but with the precaution of avoiding meaningful sequence cues like 'love-mother' or 'ugly-friend' as much as possible. The position factor was still further corrected by using two lists alternately, so that half of the subjects learned one list and half the other.

The words were presented on a rotating drum which exposed them at intervals of 1.8 sec. Each subject was told to write down the words he remembered after the first complete presentation. This constituted 'immediate recall.' The subjects then recalled and recorded as many words as they could after each second presentation thereafter, until the entire list was reproduced. All subjects read the words aloud as they appeared during the first presentation, in order to assure the absence of reading and comprehension handicaps.

One week later, without forewarning or previous intimation of any kind, the subjects were retested for recall. All S's wrote down as many words as they could remember from the list learned the previous week. No time limit was set, but less than one minute was all that was required by most S's to recall as much as they could. After the papers with the recalled words were collected, a complete list of the original words was given to each S. S was instructed to underline the words which were pleasant to him, and encircle those which were unpleasant. Then he was told to indicate the rank order of pleasantness and unpleasantness by writing numbers from 1 on down next to the words selected in each category. This served as a check on the original selection of words, without giving the S's any insight into the real purpose of the test while it was in progress. The R.O. values assigned served as a measure of vividness or affective potency of the words used. The P-U designations by the S's of the experiment confirmed the selection of words by the questionnaire almost unanimously. There was some disagreement as the R.O. of the words in each category, of course, but these are treated en masse in the results.

Table I shows the total number of critical words (P–U) recalled by all S's in each group immediately and after the interval of one week. In the few cases where the S's P–U evaluation of the words recalled differed from the rest of the group and from the selection on the questionnaire (*e.g.* a boy did not indicate 'love' as pleasant) proper corrections were made in the totals.

TABLE I

TOTAL NO. OF WORDS RECALLED

	Children		Adults	
	P	U	P	U
Immed. recall.....	26	37	27	28
After 1 wk.....	52	53	69	56

Table II gives the correlation between the frequency of recall for each word and the R.O. of affective potency or vividness, as judged by the group of S's.

TABLE II

CORREL. BET. FREQUENCY OF RECALL AND R.O. OF AFFECTIVE POTENCY

	Children	Adults
Immed. recall.....	.44	.23
After 1 wk.....	.36	.13

In Table I our hypothesis directs our attention principally to the results for delayed recall, and the relative P–U selectivity in the two age groups. The P–U division in children (52P–53U) is obviously pure chance. It remains, then, to calculate the reliability of the P–U difference in delayed recall for adults (69P–56U). M_P is 3.45 and M_U is 2.8; D is .65. The σ_P is .61 and the σ_U is .66. D/σ_D equals 3.2, which means that our difference is very reliable.

DISCUSSION

Our results show that whereas adult memory yielded a hedonistic advantage of 22 percent, a statistically reliable difference here, children remembered P and U words equally well. We do not infer from this that children do not display any hedonistic selectivity in memory at all, but we can say that 9½-year-old children show chance distribution of P and U words recalled one week after learning. What the difference would be with younger or older children, or with a longer interval before recall, or with a different kind of affective

material still remains open to investigation. The significant fact here is, however, that all conditions being equal, adults showed a reliable hedonistic selectivity and children did not. This justifies Beebe-Center's suspicion that Wohlgemuth's refutation of the principle of hedonism in memory in the face of other affirmative studies, may be accounted for simply by the fact that he used children as subjects. It also confirms our analysis of recent and more reliable studies on the basis of the ages of subjects used (pp. 435–436).

An adequate theoretical explanation for this difference is a bit beyond the scope of the present study, but two plausible explanations may be briefly indicated here. The question might be raised: When child behavior is so notoriously hedonistic and epicurean, while adult experience is so largely the opposite, how do you account for a reversal of the hedonistic selection in memory? We believe the answer is implicit in the question. The social restraint placed on hedonistic *behavior* in adults cannot be placed on natural *thought* habits or tendencies, which are primarily hedonistic. On the contrary, it would serve to exaggerate them as a sort of compensation for the social restrictions on behavior. Children, however, finding their hedonistic impulses comparatively unrestrained, do not have to resort to such automatic measures of compensation. Lest our use of the term 'compensation' prove misleading, let us hasten to explain that we do not use it in the conventional sense. There is no benign nature which gives the adult hedonistic selectivity in memory to compensate for the abuses of society. We refer merely to an automatic reaction guided by the individual's motivation, set, or activity-in-progress (Woodworth).

Another explanation might be that the distinction between pleasantness and unpleasantness in the higher mental processes has not been sufficiently well developed in children, simply because the higher processes themselves are still undergoing development. In other words, while the distinction between physical pleasure and pain may be inherent at birth, it may not extend to symbolic processes simply because these are not yet sufficiently developed.

Both explanations seem plausible to the writer, and they are by no means mutually exclusive. In any case, some development of the hedonistic tendency in memory is indicated by the results of this experiment.

Another factor evident in our results is the role of vividness (affective potency). By comparing Tables I and II we see that where the advantage was in favor of U words (immediate recall in children), the vividness correlation was appreciable. Where the P–U division was about equal, the vividness correlation was less, and where the advantage was with P (delayed recall in adults), the vividness correlation was negligible. This seems to indicate that the laws of vividness and effect are jointly operative and mutually complementary in the memory of effective material. The fact that U words are favored in the immediate recall of children would indicate that the U words were slightly more vivid on the whole than the P words on the list. As a matter of fact, the mean R.O. of affective potency for all the P words in the list of 10 was 5.6, and for all the U words 5.4, for children. For adults the mean was 5.5 for both classes of words.

The higher vividness correlation for immediate recall than for delayed recall justifies our claim that immediate recall is not a fair test for the hedonistic factor. The negative results of Lynch (**9**) and Balken (**1**) may be ignored for this reason.

One possible objection to our interpretations may be dispensed with before concluding. It might be claimed that our test for delayed recall was really only a test of over-learning, since the first words learned and most often repeated during the learning period may have been principally the same ones recalled after one week by each S. An examination of the actual memory lists of the S's, however, refutes this possible objection. The role of *attention* evidently minimized any tendency to over-learning of the earliest recalls. Different words are irregularly recalled and omitted from one list to the other, until learning is complete.

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Summary and Conclusions

An analysis of the recent experimentation on the hedonistic factor in memory led to the hypothesis, previously hinted at by Beebe-Center: that the hedonistic factor in memory is more evident in adults than in children. As a preliminary test of this hypothesis 20 9½-year-old children and 20 adults averaging 40 years in age were tested for recall one week after learning a list of words containing 5 P and 5 U words. The frequency of recall for each of the words in immediate and delayed recall for all S's was noted, and the R.O. of affective potency for the 10 words indicated by all S's.

On the basis of the results of the experiment and an analysis of all the recent studies on the hedonistic factor in recall, the following general rules may be formulated:

1. The hedonistic tendency in memory is more evident in adults than in children, which points to a *development of hedonistic selectivity in memory* from childhood to adulthood.

2. The laws of vividness and effect are jointly operative in the selection of affectively-toned items in recall, vividness being more pronounced in immediate than delayed recall, and more pronounced in children than adults.

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MUSICAL EXPRESSION: AN INVESTIGATION OF THE THEORIES OF ERICH SORANTIN

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Sorantin [1] has expounded some interesting theories as to the exact bases for our emotional experiences of music. He has approached the problem from the standpoint of the musician; after an exhaustive study of numerous compositions in which the intentions of the composer were either known or were evident from text or title, he has selected certain features which he believes to be characteristic of joy, lamentation, longing, and love.

These theories seemed to the present writer to open up a profitable field of research. If musical phrases embodying the features in question were presented to auditors in a laboratory situation, would the emotions suggested to them be the ones to be expected on the basis of Sorantin's theories?

Twenty musical passages were consequently selected, fourteen of them being taken from the illustrations in Sorantin's book, while six were composed by the present writer especially for the experiment. These six 'experimental phrases' possess certain advantages not found in the other selections, since the attempt was made to put into them all the features supposed to be suggestive of a certain emotion, and to exclude everything suggestive of any other emotion. The twenty musical phrases were all harmonized, that is, they were more than just melodies. They were played on the piano to the auditors.

The selections are indicated in the first table.

The auditors were all adult, most of them being college students enrolled in psychology. They represented various degrees of musical training. Their number varied for the different items of the experiment from 92 to 102.

With regard to methods of procedure this question arose: Should the auditors be given a list of suggested emotions to be used in making their decisions, or should they be left without this assistance? Either method has its advantage and its disadvantage. If, without the aid of any list, a large number of the observers report that a musical selection suggests to them a certain emotion, the fact is of more significance than if they merely check this term in a list. The disadvantage is that the replies are apt to be so scattering they are hard to deal with. If a check list of emotions is supplied, the

[1] Sorantin, E., *The Problem of Musical Expression*, 1932, Nashville, Marshall and Bruce.

No. of Item	Source	No. of Measures	Page in Sorantin's Book
1	Written for the experiment	2	
2	" " " "	4	
3	" " " "	4	
4	" " " "	4	
5	" " " "	4	
6	" " " "	4	
7	Mozart, Magic Flute	3	37
8	Wagner, Götterdämmerung	4	94
9	Beethoven, Sonata Op. 106	2	83
10	Mozart, Don Giovanni	4	63
11	Beethoven, Sonata Op. 31, No. 3	4	70
12	Beethoven, Sonata Op. 49, No. 1	2	84
13	Chopin, Nocturne Op. 27, No. 2	5	100
14	Beethoven, Fidelio	4	39
15	Beethoven, Sonata Pathétique	1	46
16	Schumann, Concerto Op. 54	9	101
17	Mozart, Sonata for Violin and Piano, No. 18	2	85
18	Beethoven, Fifth Symphony	4	73
19	Chopin, Ballad in G minor	2	87
20	Leoncavallo, Pagliacci	2	52

responses will be nicely bunched, and easier to treat statistically, but the data will be partly the product of the particular list used. In an experiment subsequent to the present one (which will be published shortly) several instances occurred to show how, within certain limits, the replies of the auditors were modified when different check lists were used.

It was decided to employ both methods. The phrases were first presented to the auditors with the question: What emotion is suggested to you by each passage? No information was given as to what emotions were to be expected. Then the musical phrases were played again, the auditors being supplied with a list of possible answers. This check list included the five emotions which were supposedly represented by the selections: joy, lamentation, hopeful longing, sorrowful longing, and love. To diminish somewhat the suggestive force of the list three other emotions were added: anger, fear, and disgust. It was thought that anger and fear might really be indicated in some cases. Disgust was included as a joker, but there were a few responses in this category—registering perhaps the attitude of the auditor toward the experiment! The use of the list was not insisted upon, but it was generally followed. In the data to be presented below, the first responses, marked '1st' in the tables, are those made without the assistance of any suggestions; and the second responses, marked '2nd' in the tables, are those made with the aid of the check list. Since the first responses were quite scattering, they have been grouped to a certain extent for presentation. Replies specifying sadness, sorrow, melancholy, and lamentation have been thrown together; likewise responses of happy, gay, and joyful. But great conservatism has been exercised in all such groupings so as not to falsify the intention of any observer.

The tables have been shortened by presenting only categories with responses numerous enough to have some significance, the other responses being shown as scattering. For

almost every item there are a few blanks, cases in which the auditor made no response. These blanks are not included in the tables except for the hopeful longing item, where they are so frequent that they indicate a serious confusion on the part of the observers. Occasionally this circumstance occurs in the case of other items, and mention of the fact will be made in the discussion. A further variation in the number of replies from item to item was caused by the fact that a few of the auditors took only part of the experiment.

The tables also show the features which, according to Sorantin, account for each emotion. If a phrase embodies the particular feature, an x is inserted in the proper column. In some cases it is important to know how many times the feature occurs in the item; if it occurs twice, 2x will be indicated, if three times, 3x, etc. For other features, such as major mode and accelerated tempo, only one x is of significance, and no attempt has been made to count the number of staccato notes.

The number of the item shows the order in which it was played.

Joy

Four phrases were supposed to suggest joy, as indicated in Table I.

Discussion of the Items.—Item No. 2 is one of the phrases written especially for the experiment. In addition to the features listed in the table, this item has a high trill to suggest ecstasy.[2] The phrase is clearly indicative of joy.

Item No. 10, from Mozart's Don Giovanni. Again the suggestion of joy is unescapable.

Item No. 11, from Beethoven's Sonata Op. 31, No. 3. In the first responses there are a few votes for excitement and for vigor or triumph. However, the proportion of the joy responses approaches the figure necessary to obtain a significance ratio of 3. In the second responses, under the influence of the check list, the joy replies are greatly increased.

Item No. 18, from the coda of the last movement of Beethoven's Fifth Symphony. The significance of the passage

[2] Sorantin, *op. cit.*, p. 62.

TABLE I*

FEATURES SUGGESTING JOY

No. of Item	2	10	11	18
Accelerated tempo	x	x	x	x
Ascending fourths in melody	3x	x	2x	x
Major mode	x	x	x	x
Simple harmony	x	x	x	x
Staccato notes	x	x	x	
Forte dynamics	x			x
Iambic or anapæstic rhythm	x		x	x

Responses to the Joy Items

No. of Item	2		10		11		18	
	1st	2nd	1st	2nd	1st	2nd	1st	2nd
Joy								
1st	86		73		55		27	
2nd		93		88		76		52
Excitement								
1st					11			
Vigor or triumph								
1st					13		27	
Religion or solemnity								
1st							11	
Anger								
2nd								11
Scattering								
1st	13		18		8		17	
2nd		9		5		14		27
Totals								
1st	99		91		87		82	
2nd		102		93		90		90

* The significance ratio, SR, is $\frac{\text{Difference}}{\sigma_{\text{diff.}}}$.

Let p = the proportion of responses in any one category, and let q = the proportion of all the remaining responses.

Then

$$SR = \frac{p - q}{\sigma_{p-q}},$$

$$\sigma_{p-q} = \sqrt{\sigma_p^2 + \sigma_q^2 - 2\sigma_p\sigma_q r_{pq}},$$

$$\sigma_p = \sqrt{\frac{pq}{N}}, \qquad \sigma_q = \sqrt{\frac{qp}{N}}. \qquad \therefore \sigma_p = \sigma_q, \qquad r_{pq} = -1,$$

$$\sigma_{p-q} = 2\sigma_p \qquad \text{(Edgerton's formula)},$$

$$SR = \frac{p - q}{2\sigma_p} = \frac{p - q}{2\sqrt{\frac{pq}{N}}}.$$

seems to lie between joy and vigor or triumph. In the first responses were 10 blanks, indicative of uncertainty on the part of the auditors. When the check list was given, a small majority was given to joy. The category vigor or triumph does not appear on the check list.

Summary.—Sorantin's theory for joy seems well founded. For three of the items the evidence is strong, and in the fourth case the passage suggests either joy or something in the nature of vigor or triumph.

Lamentation

There are six items in this group. The most important facts are summarized in Table II.

Discussion of the Items.—Item No. 1 is a phrase written for the experiment. In addition to the features noted in the table, this item has a tremolo in the bass which, according to the Sorantin theory, represents the trembling of fear (Page 36). The tremolo suggested to the auditors in this experiment, however, not so much fear as anger or excitement. The phrase has an unhappy mood, and in a subsequent experiment it was rewritten without the tremolo, and the responses were overwhelmingly for lamentation or melancholy.

Item No. 6, also one of the experimental phrases. This item, having no distracting features, is more successful. In the second responses 25 votes were attracted by the term sorrowful longing, which appeared on the check list. The question may of course arise as to whether sorrowful longing is distinguishable from lamentation, but there can be no doubt of the fact that the selection is definitely sad.

Now let $SR = 3$, and for q substitute $1 - p$,

$$3 = \frac{2p - 1}{2\sqrt{\frac{p - p^2}{N}}}.$$

Solving for p

$$p = .50 \pm \frac{1.50}{\sqrt{N + 9}}.$$

If

$N = 100$, $p = .64$ or 64 responses,
$N = 90$, $p = .65$ or 58 responses,
$N = 80$, $p = .66$ or 53 responses,
$N = 70$, $p = .67$ or 47 responses.

TABLE II

Features Suggesting Lamentation

No. of Item	1	6	7	14	15	20
Descending minor seconds in melody	x	3x	2x	3x	x	2x
Minor mode	x	x	x	x	x	x
Legato phrasing	x	x	x	x	x	x
Dissonance	x	3x		x		
Trochaic rhythm		x	x			
Low register	x	x			x	
Slow tempo	x	x	x		x	

Responses to the Lamentation Items

No. of Item	1		6		7		14		15		20	
	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd
Lamentation												
1st	28		85		29		9		51		54	
2nd		24		61		27		14		40		34
Joy												
1st							27					
2nd								17				
Anger												
1st	15								9			
2nd		37						9		23		
Excitement												
1st	33						13					
Vigor or triumph												
1st	10											
Religion or solemnity												
1st					25							
Calm												
1st					15		10				10	
Fear												
2nd		18				10		9		11		8
Hopeful longing												
2nd						17		17				11
Sorrowful longing												
2nd		9		25		17						25
Disgust												
2nd		12								13		
Love												
2nd						9		10				
Scattering												
1st	13		13		15		18		28		20	
2nd		1		15		9		13		2		11
Totals												
1st	99		98		84		77		88		84	
2nd		101		101		89		89		89		89

Item No. 7, from Mozart's Magic Flute. In addition to the features noted in the table this passage contains thirds in the melody, supposedly characteristic of love. As may be seen from the responses, this selection is definitely less sad than is Item No. 6. There were 9 blanks in the first responses, which, together with the scattering of replies in different categories, seem to indicate uncertainty on the part of the observers.

Item No. 14, from Beethoven's Fidelio. This selection also has thirds in the melody. The responses for this item are remarkable in that there are 27 votes for joy in the first presentation and 17 in the second. In fact, in the second responses the combined votes for joy, hopeful longing, and love are about 50 percent of the total. After a supplementary investigation it was decided that these unexpected joy votes were the result of the tempo of the phrase, which was evidently fast enough to destroy the lamentation effect. When the selection was played more slowly, it seemed much sadder. Although this explanation must be accepted as a surmise at this point, the influence of a fast tempo in destroying the effect of sadness has been abundantly proved in a later experiment. In spite, then, of minor mode, legato phrasing, dissonance, and of three descending minor seconds in the melody, the phrase is not sad unless it is played very slowly. In the first responses to this item are 15 blanks, which are additional evidence of the confusion of the auditors.

Item No. 15, the long opening measure of Beethoven's Sonata Pathétique. In addition to the features listed in the table, this selection contains an introductory ascending passage before the descending minor second, which Sorantin regards as a figure of complaint (Page 45). The item seems to suggest lamentation or anger.

Item No. 20, from Leoncavallo's Pagliacci. This also contains the ascending figure of complaint before the descending minor seconds. After the check list was supplied to the auditors, 25 of them listed the passage as sorrowful longing. The significance of the item lies between this category and lamentation.

Summary.—Item No. 6 shows that there is much truth in the Sorantin theory for lamentation. It is not clear, however, that sorrowful longing can be distinguished from lamentation. In the case of some items there were many responses for anger and excitement. Thirds in the melody apparently produced a confusion in the responses, and a moderately fast tempo operated in one case to destroy the lamentation effect.

Longing

Longing is suggested, according to the theory, by intervals of the seventh or ninth (Pp. 76 and 78). Longing is combined with joy, lamentation, or love. If the 'longing' passage contains also the features of joy, it suggests hopeful longing; if the features of lamentation, it indicates sorrowful longing. The combinations of longing and love will be reserved for a subsequent section. There are three items supposed to represent hopeful longing. The data are given in Table III.

Discussion of the Items.—Item No. 4 is a phrase written for the experiment. The first responses show a considerable scatter with such contradictory results as votes for joy and for lamentation, for vigor or triumph and also for calm. When the term hopeful longing was presented, however, almost two-thirds of the votes were attracted to it.

Item No. 12, from Beethoven's Sonata, Op. 49, No. 1. The first responses indicated joy and calm with 20 blanks. The second responses show hopeful longing, love, and joy in almost equal strength.

Item No. 17, from Mozart's Sonata for Violin and Piano, No. 18. The two ascending fourths in the melody may account for the joy replies. The item did not suggest hopeful longing to the observers.

Summary.—The replies included a great many blanks, a sign of uncertainty on the part of the auditors. The term hopeful longing did not appear in significant numbers until it was suggested by the check list. This fact raises the question whether 'hopeful longing' is the correct term. After the list was given, the phrase written for the experiment was success-

TABLE III

Features Suggesting Hopeful Longing

No. of Item	4	12	17
Melodic interval of seventh or ninth	x	x	2x
Dominant seventh chords	4x		x
Ascending melody	x		x
Major mode	x	x	x
Slightly fast	x		
Moderately loud	x		
Staccato notes		x	
Simple harmony		x	
Melodic interval of fourth			2x
Anapæstic rhythm			x

Responses to the Hopeful Longing Items

No. of Item	4		12		17	
	1st	2nd	1st	2nd	1st	2nd
Joy						
1st	18		36		25	
2nd		9		24		35
Hopeful longing						
1st	5		1		4	
2nd		60		28		9
Lamentation						
1st	11					
2nd		8				
Love						
1st	8					
2nd		12		25		
Excitement						
1st					13	
Vigor or triumph						
1st	20				12	
Calm						
1st	15		18		9	
Disgust						
2nd						12
Anger						
2nd						13
Scattering						
1st	13		17		14	
2nd		8		6		13
Totals						
1st	90		72		77	
2nd		97		83		82
Blanks						
1st	11		20		15	
2nd		5		10		11

ful in bringing forth the hopeful longing replies, but Item No. 12 showed a mixture of hopeful longing, joy, and love, while the other item was, from the standpoint of proving the theory, a failure.

There are also three items which are supposed to be suggestive of sorrowful longing. They are presented in Table IV.

TABLE IV

FEATURES SUGGESTING SORROWFUL LONGING

No. of Item	3	9	19
Melodic interval of seventh or ninth	x		
Chords of dominant seventh or ninth	2x	x	x
Descending seconds in melody	3x	x	2x
Minor mode	x	x	x
Legato phrasing	x	x	x
Trochaic rhythm	x	x	
Dissonance		x	
Slow tempo	x	x	

Responses to the Sorrowful Longing Items

No. of Item	3		9		19	
	1st	2nd	1st	2nd	1st	2nd
Lamentation						
1st	36		47		48	
2nd		18		31		25
Sorrowful longing						
1st	5		3		2	
2nd		59		21		35
Calm						
1st	48		18		25	
Fear						
2nd				15		
Hopeful longing						
2nd		16				
Love						
2nd						13
Scattering						
1st	9		14		11	
2nd		8		21		16
Totals						
1st	98		82		86	
2nd		101		88		89

Discussion of the Items.—Item No. 3 is one of the 'experimental phrases.' Without the check list the phrase suggested lamentation and calm, and perhaps a calm lament is not very different from sorrowful longing. After the list was presented, a majority of the votes is found under the heading of sorrowful longing, but lamentation and hopeful longing are both indicated also.

Item No. 9, from Beethoven's Sonata, Op. 106. Sorrow and calm are again represented in the first responses, which include 10 blanks. Even with the aid of the check list only about one-fourth of the auditors chose sorrowful longing. There were many responses for lamentation.

Item No. 19, from a Chopin Ballad. The first responses indicated lamentation and calm; the second, lamentation and sorrowful longing.

Summary.—For all three items the first responses show lamentation and calm, and it seems likely that they all suggest the same mood. Again the question is raised as to whether sorrowful longing is the right term, since it is not represented in any strength until it is suggested by the check list. It is not clear whether sorrowful longing can be distinguished from lamentation. Perhaps it may be concluded that the items suggest something similar to lamentation, but less intense than the mood of Item No. 6.

Love

There are four items which, according to the theory, should suggest love, although three of them are strongly marked with features of longing as well. The data are shown in Table V. A dolciata S-curve melody is one having an upward and downward oscillation.

Discussion of the Items.—Item No. 5 was written for the experiment. Before the list was given, joy was far ahead of love. After the list was given, a majority of the votes went to love. This item shows again the influence of the check list, but in this case both joy and love appear on the list; thus the situation is different from that of the preceding items since the term calm does not appear on the list. In the second responses 17 go for hopeful longing, an emotion similar to love.

TABLE V

FEATURES SUGGESTING LOVE

No. of Item	5	8	13	16
Dolciata S curve melody	x	x	x	x
Thirds and sixths in treble	13x	x		
Major mode	x	x	x	x
Moderate tempo	x	x	x	x
Legato phrasing	x	x	x	x
Features of longing				
Melodic interval of seventh or ninth		x	x	3x
Dominant or supertonic seventh chords	2x	4x	x	5x

Responses to the Love Items

No. of Item	5		8		13		16	
	1st	2nd	1st	2nd	1st	2nd	1st	2nd
Love								
1st	18		5		24		11	
2nd		55		14		30		21
Joy								
1st	43		29		7		7	
2nd		14		28				7
Lamentation								
1st	7		9		12		10	
2nd		9				8		17
Religion								
1st							35	
Calm								
1st	19		15		40		11	
Hopeful longing								
2nd		17		21		27		19
Sorrowful longing								
2nd						24		20
Scattering								
1st	5		21		2		10	
2nd		3		23		2		6
Totals								
1st	92		79		85		84	
2nd		98		86		91		90

Item No. 8, from Wagner's Götterdämmerung. The first responses show a considerable scatter with 13 blanks. In the second responses joy, hopeful longing, and love are represented in descending order. As an example of a love theme, therefore, the item cannot be considered a success.

Item No. 13, from Chopin's Nocturne, Op. 27, No. 2. Almost half of the first responses indicate calm. After the list was given the passage suggested love, hopeful longing, and sorrowful longing. Since the item contains features for longing as well as for love, this result is perhaps in line with the theory.

Item No. 16, from Schumann's Concerto, Op. 54. In addition to the features noted in the table, this passage is in iambic rhythm, a supposed feature of joy. The chords of this selection are somewhat like those of a hymn tune, and in the first responses almost half of the replies were based upon this characteristic. After the list was given, the votes were split among love, sorrowful longing, hopeful longing, and lamentation. The first three of these categories account for two thirds of the replies, and thus the theory is by no means disproved, although the votes for love are less numerous than in the case of the preceding item.

Summary.—Love is not an important factor in the first responses. After the check list was given, love was indicated in a majority of the replies for Item No. 5. The other three items are supposed to suggest longing as well as love, and from this point of view two of them are fairly successful.

Summary

This experiment is an investigation of the theories of Dr. Erich Sorantin, who has listed certain specific musical features which he believes to be suggestive of five different emotions. Twenty musical passages, six written especially for this experiment by the present writer and fourteen selected from the classics, were played on the piano to about 100 observers to ascertain if the emotions suggested would be those to be expected on the basis of the theories. The responses were made, first without the aid of any check list of suggested emotions, and second with the assistance of such a list.

Sorantin's theory for joy seems to have a large element of truth, and the same may be said of the theory for lamentation in the case of the passages which are free from certain distracting features.

The theories involving hopeful longing, sorrowful longing, and love are less certain. Replies involving these terms become numerous only when they are suggested by the check list. It is not clear that the terms hopeful longing and sorrowful longing are well chosen.

Passages supposed to represent hopeful longing frequently called forth responses for joy. The sorrowful longing passages likewise suggested to many of the auditors either lamentation or calm. The passages supposedly depicting love produced many replies under the headings: joy, hopeful longing, sorrowful longing, and calm. Three of these passages, however, were strongly marked with the characteristics supposed to indicate longing.

Responses are in part a function of the check list. No contradictory results were produced by introducing the list, but modifications were made like, for instance, the change from calm to sorrowful longing.

Items written especially for the experiment produced better results than did the passages selected from the classics. This does not mean that these 'experimental phrases' are better music, but since they were written with the idea of putting into them everything that the theory called for and of excluding everything that might conflict, the fact is itself something in the way of a confirmation of the theory.

Plan for Future Research.—The present investigation was for the purpose of checking the Sorantin theory for each emotion as a whole. If a phrase combines all of the lamentation features, descending minor seconds, dissonance, minor mode, etc., will it suggest lamentation? The next step will be to study the different characteristics individually to see, if possible, which features are important and which may be unnecessary. Publication of a second investigation in which this problem was attacked will follow shortly.

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THE RELATION OF VIBRATORY SENSITIVITY TO PRESSURE

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Introduction

In two previous papers (**4**, **5**) the writer has discussed the sensitivity of the fingers to mechanical vibration and to alternating electrical currents. These experiments were directed toward a study of the general nature of the sensations aroused by the various modes of stimulation. One finds in the literature two conflicting views regarding the sensory mechanisms which elicit vibratory experiences. Von Frey (**8**) has held to the view that vibratory sensations, both those mediated by mechanical vibrators and those induced by alternating electrical currents, result from the operation of the so-called 'pressure sense.' Katz (**6**, **7**) on the other hand has defended a separate 'vibratory sense.' Geldard (**3**) has discussed the differences between these two viewpoints and the empirical grounds on which the two hypotheses were based. In a survey of 400 spots on the ventral side of the arm just proximal to the wrist Geldard found 40 pressure sensitive and 19 pressure insensitive spots. The mechanical-vibratory limen for each of these 59 points was determined for a frequency of 256 cycles. The results showed unequivocally that those skin areas readily responsive to pressure were also highly sensitive to mechanical vibration, and that pressure insensitive areas were relatively insensitive to mechanical vibration. He suggests that vibratory sensations fall into a perceptual pattern of feeling of which pressure is but another temporal expression.

Problem

The study reported here was an attempt to determine not only the skin receptors involved when stimulations are made by mechanical vibration and by alternating electrical

currents, but also to study the general distribution of these receptors over different regions of the body. A further aim was to study the nature of the experiences aroused by electrical alternating currents when the resulting sensations are not of a 'vibratory nature.'

Apparatus

The apparatus used to produce the mechanical vibration was similar in principle to that described by Geldard and Gilmer (2). It consisted of an electromagnetic speaker modified in such a way that a reasonably sharp needle .17 mm in diameter vibrated as an extension of the armature. This unit was activated by an audio-oscillator with suitable amplification. The determination of the frequency, amplitude, damping, and wave form of the vibrating needle was made through the use of an independent electrical recording system. The method of measuring the thresholds of vibration has been described previously by the writer (4).

The electrical stimulations were produced by an audio-oscillator, the currents being amplified and connected to the various electrodes which will be described later. Limens for the electrical sensations were recorded in terms of power units (milliwatts). These measurements were made through the use of a standard A. C. voltmeter and milliammeter. A detailed description of the apparatus and method used was given by Gilmer (5).

Vibration Through Mechanical Stimulation

For this study a region on the dorsal side of the subject's left arm just proximal to the wrist was marked off to contain 96 sq. mm. Local orienting marks were placed in this region by the subcutaneous injection technique described by Dallenbach (1). This area was explored with the needle, one sq. mm at a time and recordings were made of 'pressure sensitive' and 'pressure insensitive' spots. The skin gradients were kept constant throughout all of the experiments. By means of a micrometer scale in a binocular microscope and a map of the skin area, one could be certain to stimulate any given spot from time to time. The results of this exploration showed that although there were some differences in the limen, no clear line of demarcation between the sensitive and insensitive pressure spots was found. This area was now examined with the vibrating needle at four different frequency levels, 64, 128, 256, and 512 cycles. 512 cycles was near the upper frequency limit of this particular skin area. In general the results showed that this entire skin area was about equal in

sensitivity; and with only a few exceptions it was more sensitive to the lower frequencies than the higher ones.

The results of this survey, where there was little difference among the various spots stimulated both as to pressure and vibratory sensitivity, showed an interesting discrepancy from the findings of Geldard (3). He found clear cut differences between these sensitive and insensitive spots. These seemingly inconsistent data led the writer to investigate whether these differences might be caused by a variation in skin texture, a distribution of end-organs, or to some other factor between the dorsal and ventral sides of the arm. To test these possibilities a bracelet of sensitivity was measured around the arm just proximal to the wrist. Rows of ten spots, one mm apart, at ten mm intervals were laid out. Since the arm measured 180 mm in circumference, eighteen rows, or a total of 180 spots were explored.

These 180 spots were explored with the needle described above and a determination was made of the pressure sensitive and pressure insensitive spots. There were relatively more pressure sensitive spots on the dorsal side of the arm than on the ventral side. 'Pressure' was reported in most cases only when a distinct 'heavy pressure' was sensed.

The vibratory threshold was obtained on each of these 180 spots for an arbitrarily chosen frequency of 256 cycles. In general, it can be said, that the limens for those areas on the dorsal side of the arm were relatively low as compared to those on the ventral side, save at the pressure points where vibratory sensitivity was very great. On the ventral side of the arm there was a well marked difference between the sensitive and insensitive spots. Coming down the inside of the arm from the dorsal side this difference became more and more pronounced, becoming less distinct as one proceeded up the other side again toward the dorsal area. It is interesting to note, further, that the 'pressure sensitive-vibration sensitive' spots had relatively the same limens regardless of their particular distribution in the skin. Of the 180 spots explored 17 of them were sensitive to pressure. All of these were highly sensitive to mechanical vibration.

Vibration Through Electrical Stimulation

After a completion of the exploration with mechanical vibration a similar survey was made using alternating electrical currents, with 256 cycles, as the stimulus. A small needle similar to the one described above served as the active electrode with a large copper handgrip serving as a neutral electrode. The spots were not the same as those stimulated in the experiment on mechanical vibration, but the same general skin areas were explored for both pressure and electrical sensitivity. Some interesting sensory experiences resulted. When spots insensitive to pressure were stimulated the experience of 'burning pain' was obtained. Stimulation of pressure spots gave sensations similar to those produced by mechanical vibration. Hereafter, we shall speak of them as 'vibration sensations.'

The results of surveying these 180 spots gave 30 pressure sensitive spots which also yielded strictly 'vibratory sensations.' Seven spots were reported as giving vibration with only 'light pressure.' All spots not yielding vibration gave either one of two other patterns, a 'burning pain' or a 'burning vibration.' This latter can be described as a 'sharp burn' superimposed upon a feeling of vibration. The 'burning pain' has no vibratory content whatsoever. In general there were more vibration spots on the dorsal surface of the arm than on the ventral. The limens for the vibration sensitive spots were with very few exceptions higher than for those where the experience was of 'burning pain.' The 'burning vibration' limens lay between these two extremes.

Since some earlier work by the experimenter has shown that the palmar side of the hands yields vibratory experiences to alternating electrical currents, the next problem involved, therefore, was a study of the various regions of the body to determine those areas giving vibration sensations.[1] This survey was made with a copper electrode 2 mm in diameter. It was found that the only large skin areas of the body yielding the vibratory patterns to the electrical currents were the

[1] Mr. Joseph Weitz and the writer served alternately as observer and experimenter in this series.

palms of the hands and the soles of the feet. All other regions gave the experience of 'burning pain.' An exploration with much larger electrodes gave virtually the same data.

The Distribution of 'Vibration Sensitive–Pressure Sensitive' Spots

The possibility that the thickness of the skin had some effect on producing vibratory experiences such as were found on the bottom of the feet and on the palms of the hands was investigated by placing pieces of fresh meat between the electrode and the skin, thereby 'thickening' the skin. By this method it was possible to set up 'vibratory experiences' on the various regions of the body. Similar results were found by applying large wet electrodes. However, a more extensive survey of the body with the 'thickened skin' showed that rather large skin areas in the middle of the back would not yield vibratory experiences, whereas upon moving to some adjacent region these sensations could be aroused. Several of these skin areas were outlined and by using smaller and smaller wet electrodes it was possible to narrow down these regions to a size where the vibration experiences resulted when stimulations were made with the 2 mm dry electrode. By exploring this area with the needle a single spot was found which was both pressure sensitive and vibration sensitive. Moving away from this spot, in some cases a distance less than one-half of one mm the subject felt a sensation of 'burning vibration'; going away from the pressure sensitive spot still further gave the pattern of 'burning pain.' This suggests some kind of 'spreading out' effect of the stimulations.

The normal sensations aroused at the finger tips by alternating currents has been reported elsewhere by the writer (**5**). Here the sensations elicited were investigated for frequencies ranging in steps from 64 to 12,500 cycles. Vibration was experienced up to frequencies around 2000 cycles, frequencies above this range giving the feelings of extreme warmth, finally going into patterns of psychological heat at frequencies higher than 8000 cycles. It is known that a frequency range around 2000 cycles is near the upper limit of sensing mechani-

cal vibration at the finger tips (4). To see what effect there would be on the various sensations elicited through stimulation by alternating electrical currents, the skin on the finger tips was 'thinned' by the use of sandpaper. A partial 'thinning' of the skin caused the sensations elicited to be those of 'burning vibration,' whereas removing a greater portion of the epidermis caused the response to the currents to be the characteristic 'burning pain.' The limens obtained under these conditions bore the same relationships as those reported above for other regions of the body. With the epidermis intact the sensations of 'vibration' came in with relatively high thresholds. With almost complete removal of the epidermis we found the 'burning pain' with low thresholds. The 'burning vibration' thresholds were intermediate between these two limits.

As stated earlier, the only regions of the body giving vibratory sensations to the electrical currents were the palms of the hands, the soles of the feet and on pressure sensitive spots in any general region of the body. One interpretation would be that on the palmar sides of the hands and the soles of the feet there is a general vibratory sensitivity because here the vibration sensitive end-organs are closely packed together, being sparce in other regions of the body. One can, however, get in these regions isolated spots not sensitive to vibration, which yield either the 'burning pain' or the 'burning vibration.' As one means of checking the distribution of these vibration sensitive spots a band of skin was explored from the middle of the arch around to the top of the foot with the 2 mm dry electrode; stimulations being made every 2 mm. The results showed that sensitivity went from that of general vibration at the arch of the foot, through 'burning vibration' on the side of the foot, into patterns of 'burning pain' when approaching the top of the foot. Some few spots yielded vibration on the sides and the top of the foot—these were also pressure sensitive.

These data support the theory that spots sensitive to pressure are also highly sensitive to mechanical vibration. Furthermore, that the only spots on the surface of the skin

mediating 'vibration' patterns from stimulation by alternating electrical currents are those which are also pressure sensitive.

Summary and Conclusions

1. The sensitivity of different regions of the skin to stimulation by mechanical and electrical vibration was investigated.

2. The regions of the skin most sensitive to mechanical vibration were those spots which were also highly sensitive to pressure.

3. Pressure insensitive spots were relatively insensitive to mechanical vibration.

4. There was a marked difference between the dorsal and ventral sides of the arm with respect to vibratory sensitivity by mechanical stimulation.

5. The only spots on the surface of the skin yielding 'vibratory sensations' to stimulation by alternating electrical currents were those points which were highly sensitive to pressure.

6. Electrical stimulation of spots near, but not on, pressure points gave the experience of 'burning vibration.'

7. Electrical stimulation of local skin areas not containing pressure sensitive spots yielded the experience of 'burning pain.'

8. The only skin regions of the body mediating 'vibratory experiences' to the alternating electrical currents were the palms of the hands, the soles of the feet, and pressure sensitive spots in any general region of the body.

9. The limens for those spots yielding 'vibration' to the electrical stimulation were consistently higher than those for which the experience was of 'burning pain.' The limens for the 'burning vibration' were intermediate between the two.

10. Possibly skin structure and the distribution of pressure end-organs determine the sensitivity of any region of the body to mechanical and electrical vibration.

11. Our data support the hypothesis that vibration sensations form a perceptual pattern of feeling of which pressure is but another temporal expression. Vibration, therefore, may be thought of as 'interrupted pressure.'

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A COMPARISON OF PREFERENCE AND MOTOR-LEARNING MEASURES OF HANDEDNESS

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I. *Introduction.*—The use of certain conventional motor-skills tests as measures of laterality was reported by Beck (1) in a recent paper. Each of his subjects, on successive trials, alternated hands in a given motor performance; he thus was able to measure objectively the level of performance of either hand on the pursuit rotor, triple plate tapping, and like tests. He could also evaluate the difference between the skills of the two hands, in terms of total score for each. The level of correlation between hand-differences on various tests varied from .40 to .71, indicating, according to Beck, a common factor of laterality in the performances.

II. *Purpose.*—It was the purpose of the investigation to be reported here to compare the motor-learning measures of handedness described above with measures determined from 'habitual' hand preferences in a number of simple situations where choice of hand for a given task was the only significant variable. (For a more complete discussion see Buxton, 3.) It was thought that, if the motor ratios could possibly be validated in this way, they would provide a simple time-saving method of testing for laterality in clinical and other situations.

III. *Tests Used.*—The habit-preference measures of handedness were derived in the following way. It was assumed that there are all degrees of handedness from extreme left to extreme right, and, also, the greater the dominance of either side the more often will the hand on that side be used, in preference to the non-dominant hand. Thus if an individual in this investigation is confronted with 40 situations in which he is free to use either hand to accomplish a task, and he uses the right hand 35 times and the left 5, he is said to be *more* right-handed or right-dominant than the subject who uses the right hand 25 times and the left 15.

It is evident that such a group of tests does not take into account the fact that 'natively' left handed individuals may have been forced to use the right hand to an even greater degree than individuals who were somewhat right handed as young children. However, no claim is made that any behavior except present habit tendencies is sampled; this is the most frequently used method of determining laterality. Per-

formance was chosen instead of the questionnaire because of its seemingly closer approach to reality.

In order to secure a large number of simple situations, three type-tests were chosen: throwing, near and far reaching for objects, and brushing imaginary lint from the clothing. Each of these was given ten times, in slightly varying ways and positions, arbitrarily selected by the experimenter. To these 30 choices of hand was added a pegboard situation in which 10 pegs were strewn fan-fashion before the subject and he was simply told to replace them in the board. All the detailed variations in the preference testing situations will not be described. Suffice it to say that various body positions and type of throw characterized the throwing test, and that the pegs for the peg-board were placed so that either hand could reach any peg, and for the reaching test, a solid metal cylinder was placed about the room at differing heights and at near and far reaching distances. All tests were given in a definite order and with dispatch. A score of + 1 was given for each time the right hand was used in the throwing, reaching, brushing, and peg-board tests, a score of zero for use of both hands or noticeable indecision (which, although rare, did occur) and − 1 for each choice of left hand. As an added test, 5 paired trials were taken on a dynamometer, with adequate rest periods, and the stronger hand in each pair of trials given an arbitrary weight twice that for choice of hand in each of the other tests. On the combined scale, then, an extremely right-handed individual might receive a score of 50, and an extremely left-dominant individual a large minus score.

Every effort was made to put the subject (in most cases a college freshman, although a few high-school students were included) through the test series rapidly, and to keep his attention off the performance of these tasks. This was very necessary in preventing self-consciousness, which to the extent that it entered in probably invalidated the results. The only evidence concerning the control of this factor was the experimenter's subjective judgment that to a reassuring degree he was successful in keeping attention turned from the details of the testing situation. It was often the case that an adult subject took the whole tests series as a game of following instructions, with the attitude of 'now what?'

The arbitrariness of this whole procedure is recognized, and no attempt is made to say what score represents an absolute amount of laterality in any case. The scale does serve, however, to rank an experimental group in order of frequency of preference for one hand or the other, and under our principal assumption, this is an expression of the relative degree of laterality. When individuals are classified by such a scale the correlation technique may be applied to determine the relation of varying strengths of preference, as measured by the whole battery of tests, or each sub-test, to other variables.

The motor skills tests and procedure used were identical with three of Beck's, the pursuit rotor, triple plate tapping, and motility rotor (2). Suffice it to say here that the pursuit rotor is a test of skill in following with a stylus a silver dot which revolves in a circle on a phonograph-like turntable. A fairly great amount of learning is shown in a dozen trials with either hand. The motility rotor is a hand shop-drill equipped with a device for recording the number of revolutions of the handle. The triple plate tapping test calls for speed in stylus-tapping a triangular pattern.

IV. *Procedure.*—Each subject was given the motor skills tests at the first of two test periods. The motor skills were administered with alternate trials for the two hands exactly as described by Beck (1). The total scores for each hand were combined into a ratio, the numerator of which was the difference between the two hands and the denominator the sum of the totals. Such a ratio shows the relative superiority of one

hand or the other in performing these tasks. Whereas Beck used as a measure the percent by which the superior hand exceeded the inferior, the ratio used in the present study takes account of the 'absolute' level of skill of both hands. In other words, an intermanual difference of given size may be very significant or insignificant in relation to a low or high level of achievement, and the ratio here used, with 'absolute' level of achievement accounted for by the denominator, attempts to more satisfactorily meet this problem.

Motivation is self-provided with these tests, for they are interesting to nearly all subjects. The administration of the preference tests was accomplished as described above, during a second testing period.

V. *Results.*—We shall examine the reliabilities and inter-correlations for the test batteries separately, later comparing the two. In Table I it is shown that the odd-even reliabilities

TABLE I*

$N = 86$

	Pegboard	Brushing	Throwing	Reaching	Dyn.	All
Pegboard	.87(.93)	.59	.62	.63	.49	.77
Brushing		.30(.50)	.59	.63	.40	.56
Throwing			.88(.94)	.70	.57	.75
Reaching				.79(.88)	.44	.64
Dynamometer					.67(.80)	.60
All						.88(.94)

* The coefficients in parentheses are estimations, by the Brown-Spearman formula, of reliabilities for full-length tests. The *r*s in the last column were computed by plotting each test against the remainder of the tests, with the exception of the pooled reliability which is explained in the text.

of the peg-board, throwing and reaching tests are of a relatively high order, but that the brushing test is quite unsatisfactory and the dynamometer performance is also inconsistent. The reliability of the battery, total odd scores on the four tests plotted against total even scores, is probably high enough for use of this group of tests in individual cases, which is usually the most desired application of laterality findings. The consistent level of inter-correlation (average $r = .59$) may be interpreted to mean that a common factor (laterality) is influencing scores on all the tests.

We may see from Table II that while the reliabilities of the difference-ratios for the manual skills are of fairly satisfactory size, the inter-correlations indicate that direction and degree of superiority of either hand is specific to the testing

TABLE II *

$N = 43$

	Pursuit Rotor	Tapping	Motility Rotor
Pursuit rotor	.53(.69)	.14	.06
Tapping		.65(.79)	.13
Motility rotor			.81(.89)

* Coefficients in parentheses same as in Table I.

situation and not predictable from one test to another. These results are in sharp contrast to the inter-correlations of Beck, shown in Table III. At present no satisfactory explanation

TABLE III *

$N = 43$

	Single-tap.	Spool-pack.	Motility Rotor	Triple-tap.
Spool packer	.42			
Motility rotor	.55	.50		
Triple tapping	.55	.47	.71	
Pursuit rotor	.47	.41	.66	.65

* Taken from Beck (1), p. 269.

of the difference can be offered, in view of the adequate reliability coefficients. The possible cue, of course, is that this group, smaller than Beck's and without so large a number of individuals classified as sinistral, did not produce a large enough range of talent to emphasize the relationships which did exist. On the other hand, it is difficult to conceive that a jump from the small *r*s here reported to *r*s the size of Beck's could have been produced even by doubling the range.

It may be noted in the thesis by Beck (**2**) that when these inter-correlations were computed for the group of dextrals, the correlation between the motility rotor and triple plate tapping was −.049, between the pursuit rotor and tapping, +.049, and between the motility rotor and pursuit rotor, +.203. The indication is thus that almost no prediction of degree of handedness is possible within a group of right handed individuals, so that the hand-differences are not at all indicative of the degree of whatever common laterality may exist.

The directly-sought findings of this investigation may be ascertained from Table IV, which shows inter-correlations of all the tests used, and the pooled batteries also. From it we see that: (1) correlations with the least reliable preference test, brushing, are lowest of all given, averaging only .07; (2) correlations with the most specifically habituated preference test, throwing, are highest, averaging .29; (3) correlations of the motor-skills separately with the pooled preference tests average .33; (4) correlations of the preference tests with the most 'familiar' manual skill, the drill, are higher than with either of the other two skills (rotor, tapping)—the average

TABLE IV*

$N = 43$

	Pegboard	Brushing	Throwing	Reaching	Dyn.	Pooled Pref.
Pursuit rotor	.09	.03	.15	.13	.06	.22
Motility rotor	.34	.11	.63	.46	.37	.40
Tapping	.32	.08	.14	.15	.23	.23
Pooled motor	.31	.07	.25	.26	.33	.45

* In order to pool the motor-skills scores it was necessary to convert the ratios into percentile ranks, then average the percentile ranks for each subject. There is some error inherent in the procedure, but it seemed the best available for the purpose.

correlation with the drill is .39, with the rotor, .11, and with tapping, .19; (5) the average correlation of the performance tests with motor skills pooled is .24; and (6) the fact perhaps most significant is that the correlation between the pooled motor-skills (for explanation of the method of pooling see legend of Table IV) and the pooled preference scores (pooled by simple addition) is .45.

We are thus led to the conclusion that although there is a definite relationship between the two types of tests when the batteries each are pooled, the two types of tests are in general sampling behavior determined by many factors not common to both. There is a hint in the increased size of correlation between the more familiar motor performance (drill) and the preference tests that the manual skills here tested in the early stage of learning are affected by differential factors in the learning process. The writer advances the hypothesis that as the manual skills are better learned they yield results more

like the results of the preference tests, and proposes to check this hypothesis in the near future.

VI. *Summary.*—1. Manual-skill measures of handedness proposed by Beck were compared with a battery of preference tests to determine whether or not the same principal function (laterality, or dominance) was tested by each type of test.

2. The reliabilities of the three motor-skills ratios (rotor, drill, tapping) were relatively satisfactory; the brushing and dynamometer tests were not so satisfactory as to reliability, but the throwing, reaching, and peg-board reliabilities were high.

3. The preference measures inter-correlated at a level interpreted as showing some common determiners, assumed to be laterality of function.

4. The motor-skills measures did not correlate closely enough with each other or with the preference tests to indicate significant communality. However, when each of the two batteries was pooled, the correlation between them was .45, indicating that in a very general way the tests were sampling similar behavior; this level of correlation certainly does not permit substitution of either battery of tests for the other.

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THE LABORATORY COURSE IN PSYCHOLOGY: III. HUMAN AND ANIMAL LEARNING IN THE MAZE

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One of the most consistently used experiments in laboratory psychology is maze learning. Some form of the grooved maze, in which the pattern is traced with a stylus, has usually been employed as apparatus. As is well known, this maze has proved to be far from satisfactory in most drill laboratories.

A more satisfactory apparatus, which is described below, is one: (1) which has two approximately equal forms available; (2) which permits each of the two partners to complete the learning of one form within the ordinary laboratory period of two hours; (3) whose learning is characterized by procedures that are readily recognized and described by S; (4) which yields a learning curve that may be interpreted in terms of the elementary student's background in the field; (5) which may be constructed in a local shop at small cost. Some laboratories undoubtedly would like to adopt a maze which already has adequate norms for comparison with individual data. The following description is offered so that others may profit from our experience over a period of several years at Minnesota.

We have substituted the Miles type of high relief finger maze (**3**) for the grooved type (**1**). A modification of the Warden maze pattern (**5**) was used. Contrary to Warden's pattern, there are no right angled segments at the end of blind alleys, and the sequence of choices was changed in Form A to R L R R L L R L R R L R; and in Form B to L R L L R L R R L L R L. The linear dimensions were kept approximately the same as in Warden's maze.

For the animal experiment, a maze with one pattern of the human maze, Form A, was constructed as follows: an elevated pathway two inches wide, resting on the tops of

2 × 2's, forty inches long, extended about 12 feet along the classroom. Between the class and the maze was a one-way vision screen (wire window screen painted white) brightly illuminated on the maze side. This, when the general illumination of the room was relatively dim, effectively eliminated the students from the rat's vision.[1] The animal experiment was conducted in the class with precautions and procedures similar to those employed (**2**) with our less satisfactory set-up (**4**) for animal learning.

For comparison with each other the group data for human subjects (university students) on Maze A and Maze B and for rats on Maze A are listed in Tables I and II. These data may be considered as norms with which to compare individual performance. It is seen that for human subjects, performance on Maze A and Maze B are strictly comparable with one

TABLE I

AVERAGE TIME AND ERRORS FOR GROUP DATA IN MAZE LEARNING

Trial	Human Maze				Animal Maze	
	Maze A (N = 52)		Maze B (N = 53)		Maze A (N = 12 Rats)	
	Time (Sec.)	Errors	Time (Sec.)	Errors	Time (Sec.)	Errors
1	79	5.4	42	5.4	402	20.9
2	44	4.2	32	3.9	75	8.8
3	32	3.1	27	3.5	41	5.7
4	28	2.8	24	3.3	24	3.2
5	26	2.9	23	3.2	34	3.3
6	24	2.5	23	3.0	26	2.7
7	22	2.4	21	2.5	28	2.8
8	21	2.0	20	2.1	26	1.6
9	20	1.6	20	2.6	20	1.7
10	20	1.5	19	2.1	28	.9
11	18	1.6	18	1.7	19	1.1
12	18	1.2	18	1.8	17	.7
13	17	1.4	18	1.6	15	1.0
14	17	1.1	18	1.7	14	.5
15	16	1.2	17	1.2	15	.1
16	15	.9	17	1.4	*21*	*3.2*
17	16	.8	16	1.1	*18*	*1.6*
18	15	.7	15	1.0		
19	15	.7	14	1.0		
20	15	.6	14	.8		
21	15	.5	14	.7		
22	15	.5	14	.8		
23	14	.4	14	.8		
24	14	.4	14	.6		
25	14	.4	13	.5		

[1] The writer is greatly indebted to Dr. S. R. Hathaway who suggested and supervised the construction of this whole set-up for the rats.

exception. In the first 2 or 3 trials the time is less on B than on A. This is undoubtedly due to the fact that B was done after S had seen a subject perform on Maze A.

The rats are slower and make more errors than humans on the first three trials. Otherwise the trend of learning is similar to that of humans, although most of the errors are eliminated for the animals by the fifteenth trial. Prior to the 16th trial for the animals the maze pattern was altered by making the 7th choice left instead of right. Interference is shown by scores on the 16th and 17th trials. When trials are continued, the interference disappears at about the 20th trial.

Location and frequency of errors are shown in Table II. Examination of this table shows that the rats tend to learn

TABLE II

FREQUENCY AND PLACE OF ERRORS IN MAZES

Maze Pattern	Subjects	Blind Alley Number											
		1	2	3	4	5	6	7	8	9	10	11	12
A	6 Rats	58	37	29	41	15	18	21	49	11	7	17	10
A	38 Humans	23	87	66	200	98	226	99	207	104	271	126	40
B	38 Humans	38	85	94	244	68	166	173	307	77	299	107	46

the end of the maze first while the humans, with the exception of the last blind alley, tend to learn the first part of the maze first. Errors that are difficult for humans to eliminate (choices 4, 8, and 10) seem to have consistent location in the series in the two maze patterns.

Both these experiments have proved to be highly interesting to the students and have made worthwhile contributions to our laboratory course.

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THE INFLUENCE OF A SHORT PRELIMINARY EXAMINATION OF LEARNING MATERIAL

BY MINNA R. GROSSMAN AND HULSEY CASON

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General.—The somewhat conflicting results of studies of the relative efficiency of Massed and Distributed learning are functions of the learning activity used and the method of distributing the learning sessions. In the present experiment we have studied the influence of a short preliminary examination of learning material on the efficiency of learning. The total time used in Massed learning was 30 minutes, and in Distributed learning, six minutes were allowed for the short preliminary examination and 24 minutes were allowed for the later learning. As learning materials we used (1) paired associates, (2) series of familiar words, and (3) meaningful reading material. Two equalized sets of each of the three kinds of material were used with each subject, one set with Massed learning, and the other set with Distributed learning. Each test was of such a length that complete learning was practically impossible.

Material.—(1) Paired Associates Nonsense Syllables. The syllables were selected from Cason's (1, 201) list of nonsense syllables, and there were two lists of 12 pairs each.

(2) Series of Three-Letter Words. The words were selected from Cason's (1, 202) list of familiar words, and there were four lists of 24 words each.

(3) Meaningful Reading Material. We used the two standardized reading tests dealing with the Declaration of Independence and the American Revolution in the Iowa Comprehension Test (2), Series D1 and D2.

Procedure.—The two sets of each of the three kinds of material and the temporal order of the Massed and Distributed learning were rotated in such a way that the comparisons made are entirely valid. The total time of 30 min-

utes was divided between the three kinds of learning material in the following way.

	Learning Periods	
	Massed	Distributed
Paired associates	7½ min.	1½ and 6 min.
Series of words (for each of two series)	3¾ min.	¾ and 3 min.
Reading material	15 min.	3 and 12 min.

The subjects were tested immediately after the Massed learning, and immediately after the second of the two Distributed learning periods. The longer of the two Distributed learning periods in all cases occurred 24 hours after the short preliminary examination. When Massed learning came first, the short preliminary examination took place 24 hours later; and when Distributed learning came first, the Massed learning took place 24 hours after the longer of the two Distributed learning periods.

The 27 university student subjects were taken individually, they were told orally how they would later be tested, they were handed the typed learning material and were allowed to study it in their own natural way except that in the short preliminary examination they were asked to examine the whole set of material.

Results.—In the paired associates tests, a score of one was given for every syllable recalled. In the tests with series of words, a score of one was given for each word recalled and an additional score of one for each word in the correct position with respect to the preceding and following words. With the reading material, a score of one was given for each idea recalled.

The principal results of our study are given in Table 1, and the results show that the scores for Massed and Distributed

TABLE 1

THE INFLUENCE OF A SHORT PRELIMINARY EXAMINATION OF LEARNING MATERIAL

	Paired Associates		Series of Words		Reading Material	
	Massed	Distributed	Massed	Distributed	Massed	Distributed
N	27	27	27	27	27	27
Av.	4.1 ± .4	4.2 ± .2	63.1 ± 2.6	57.8 ± 2.2	23.4 ± 1.0	23.6 ± 1.1
Mdn.	4.0 ± .5	4.0 ± .3	63.5 ± 3.3	60.0 ± 2.8	23.0 ± 1.3	23.0 ± 1.4
S. D.	2.7	1.8	19.9	17.2	7.9	8.7

learning were practically the same for the paired associates and for the reading material. The scores were slightly higher for Massed than for Distributed learning with the series of words, but these differences are not reliable. The number of individual subjects making a higher score under Massed and Distributed learning were as follows.

	Paired Associates	Series of Words	Reading Material
Higher under Massed learning	12	17	11
Higher under Distributed learning	11	9	15
Making the same score under the two conditions	4	1	1

Conclusion.—The Distributed learning periods which we employed were different from all those used by previous investigators, and our results indicate that a short preliminary examination of learning material does not improve the efficiency of learning. Our study supports in a general way the thesis of Ruch (3, 19–20) that the relative value of Massed and Distributed learning depends upon the kind of learning activity and the conditions of learning.

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